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CHILLING REQUIREMENTS FOR OPENING OF BUDS ON DECIDUOUS ORCHARD TREES AND SOME OTHER PLANTS IN CALIFORNIA

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CHILLING REQUIREMENTS FOR OPENING OF BUDS ON DECIDUOUS ORCHARD TREES AND SOME OTHER PLANTS IN CALIFORNIA[1]

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INTRODUCTION

DURING SPRING and early summer in each of the last fourteen years, observations have been made in different districts of California to learn the effects of winters on the opening of leaf and flower buds. Of course, the time of opening of buds in spring is determined in part by spring temperature and in part by the nature of the species concerned: buds of some species will open at lower temperatures than buds of others; even with each at its most favorable temperature, buds of some species will open faster than others. The kind of winter through which they have passed, however, also influences the time when buds of most deciduous species will open. In parts of California, leaves and flowers do not appear on trees and bushes of some kinds as soon as there has been enough warm spring weather: the winters do not supply as much chilling weather as the buds must have before they will respond as quickly and uniformly to spring warmth as they do in colder climates.

Nearly all trees and bushes that survive cold winters and that shed their leaves in autumn will make slow, straggling response to warm spring weather unless their special chilling requirements[7] have been satisfied. The same is true also of some herbaceous plants that die down in autumn to buds underground. This condition in the buds that prevents or retards their opening at favorable temperatures for growth, until after some weeks of chilling, is generally called the "rest period" by plant physiologists.

In sections where cold winter weather begins by the first of November,

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[7] Coville, Frederick V. The Influence of cold in stimulating the growth of plants. Jour. Agr. Research 20(2):151–60. 1920.

the chilling requirement of nearly all kinds of plants will be fully satisfied by the first of February. Before February the buds are dormant partly because they are in the rest period; after that time they are dormant only if it is too cold for growth. In sections where November is warm and most of the days in December and January are rather cold, the buds may begin to open in warm weather late in January or early in

Fig. 1.—Northern Spy apple tree photographed June 18, 1930, in Berkeley, California, to show greatly delayed, uneven growth from the buds, after an especially warm winter.

February, but much more slowly than if the chilling weather had lasted longer. Some kinds of plants require much more chilling than others. Two or three weeks or less is enough for the almond,[8] while three months or more of chilling temperature may be required before buds of some varieties of apples will open normally.

[8] Hodgson, Frank R. Observations on the rest period of deciduous fruit trees in a mild climate. Amer. Soc. Hort. Sci. Proc. 20(1923):151–55. 1924.

The temperatures that will cause the quickest emergence of buds from the rest period are not known from exact experimentaton with the different species of trees; but we can be reasonably certain, from observation in orchards, that temperatures of 33° to 40° Fahrenheit are as good as freezing temperatures, if not better. Exposure of buds to temperatures that average about 48° will break the rest period, but a longer time is required than in colder weather.

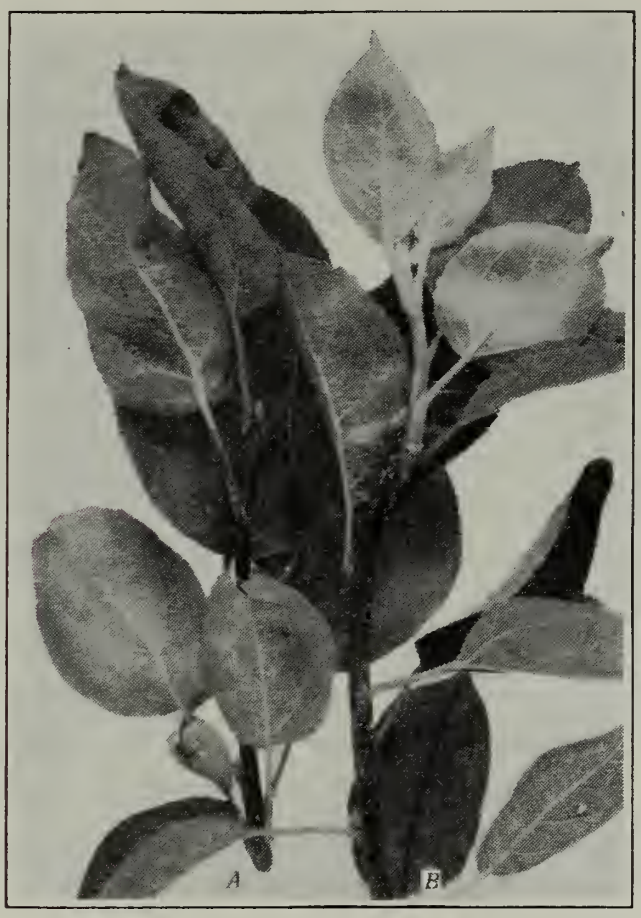

Fig. 2.—Two apple shoots cut back May 29, when they were both growing at the tip, and photographed July 7, 1936. Shoot *A* was cut back to a full-grown leaf on rather hard wood; the end bud left was far into the rest period. Shoot *B* was growing more than shoot *A* and was cut back to a leaf two-thirds grown on rather succulent wood; the end bud left was not too far into the rest period for the wound stimulus and the end position to cause growth.

Some of the buds, even on trees of varieties with the longest chilling requirement, will grow without being chilled, but only after a long time. For example, peach, apple, or pear trees, on which the buds would open in March after a little more than two months of temperature ranging from 32° to 48° F, will have a few buds opening at a time in April, May, and later, after much warmer winters. In the spring of 1930, after a

winter with very little chilling weather, no buds opened on the Northern Spy apple tree shown in figure 1 until late in May, and on several twigs no buds had started by June 18, when the photograph was taken. Some buds were just starting by July 15. If December, January, and February had been considerably colder, with March and April as warm as they were, many more of the buds would have opened, all nearly together, before April 15.

Certain other influences may be substituted for part of the chilling requirement. After a month or more of chilling weather, buds can be made to open normally if they are exposed to an atmosphere containing certain amounts of ether, chloroform, ethylene, or some other substances; if they are exposed to X rays; if wounds are made near them; or if they are treated with certain oils.

Because these special treatments tend to be effective only after there has been some chilling or long-continued dormancy to cause partial emergence from the rest period, they have been used by scientists to determine when the rest period is most profound. Usually none of them will cause growth if the treatment is made from a few weeks after the bud is formed in summer to a few weeks after leaf fall. For example,[9] apple buds will not usually respond to treatment with ether until there have been four or five weeks of chilling weather after leaf fall, and they respond better after there have been five or six weeks of chilling. Such observations indicate that the buds go into the rest period gradually after they form, and are most profoundly in it during late summer, autumn, and early winter, gradually emerging after leaf fall, emergence being much faster at temperatures below 48° F than at higher temperatures.

One of the easiest methods of telling when a lateral bud on a shoot is completely in the rest period is to cut the shoot back to just above that bud, so that it becomes the end bud. If it is just going into the rest period, its new position as an end bud plus the rest-breaking influence of the pruning wound may cause it to grow (fig. 2, *B*). If, however, the bud is profoundly in the rest period, these influences will not be strong enough to cause it to grow (fig. 2, *A*). Likewise, if a tree has stopped growing because the soil is too dry, even as early as June or July, an irrigation, or a rain, may not cause any shoot growth in the same season: the buds may all be far enough into the rest period to require chilling, or injury, before they will grow.

[9] Howard, W. L. An experimental study of the rest period in plants. Physiological changes accompanying breaking of the rest period. Missouri Agr. Exp. Sta. Research Bul. 21:1–72. 1915.

The amount of chilling required tends to be a little less for flower buds than for leaf buds. Trees of the apple and the pear that are not chilled enough before spring show less leaf growth at full blossom than trees that were chilled longer (fig. 3), even though with these species leaves and flowers are borne from the same buds. The difference is more striking on trees of peaches, apricots, plums, and cherries, which do not produce flowers and leaves from the same bud. North and east of California, where there is enough winter chilling to break the rest period com-

Fig. 3.—Blossom clusters of Delicious apple: *A*, adequate chilling; leaves slightly more advanced than flowers; *B*, inadequate chilling, flowers more advanced than leaves.

pletely, a tree of these stone fruits may be heavy with foliage by the time all the flowers have fallen. On the other hand, in a section where there is very little winter chilling, there is apt to be little foliage showing when the flowers have fallen and some of the fruit is ½ inch in diameter.

The flower begins to form in a bud in summer rather soon after its leaf is formed. Development in the flower parts continues during late summer, autumn, and winter, even if the weather is continuously warm; but that development is much slower than it would be after a period of chilling. For example, all the leaves were cut from two Lovell peach trees[10] on September 9, when a microscopic study detected the first suggestion of flower parts (fig. 4). One tree was left in a warm greenhouse at temperatures above 60° F and one was placed in a storage room at the freezing point, 32°. On November 25 this tree was put back into the greenhouse. Buds from each tree had been examined several times dur-

[10] Chandler, W. H., and W. P. Tufts. Influence of the rest period on opening of buds of fruit trees in spring and on development of flower buds of peach trees. Amer. Soc. Hort. Sci. 1933. Proc.30:180–86. 1934.

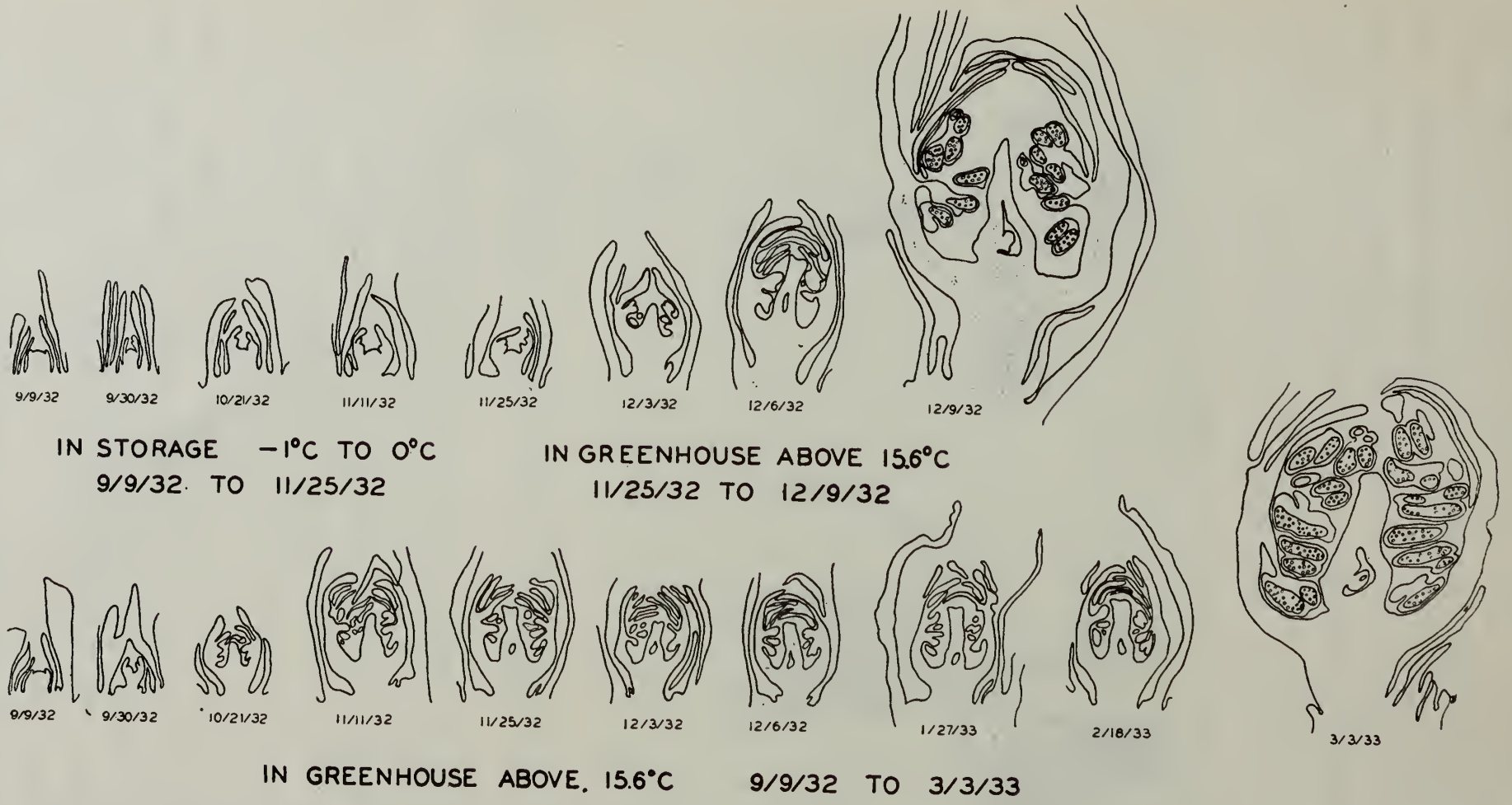

Fig. 4.—Cross sections of fruit buds of Lovell peach taken at different times of the year and equally magnified to show growth of the flower parts. The little crown in the bud, as shown at the centers of the smallest sections, grows upward into a flower, all parts of which are folded in the bud before it opens, as shown in the largest sections. Buds for the lower sections were taken from a tree kept continuously in a warm greenhouse; buds for the upper sections from a tree left in storage at 32° F (0° C) until November 9, then placed in the same warm greenhouse.

ing the period. Those on the tree in the warm greenhouse had developed steadily. Those on the tree held at 32° had developed hardly at all, but after the tree was put back into the warm greenhouse, they advanced in 11 days as far as those continuously in the greenhouse had advanced in 46 days, and in 14 days as far as those continuously in the greenhouse advanced in 133 days.

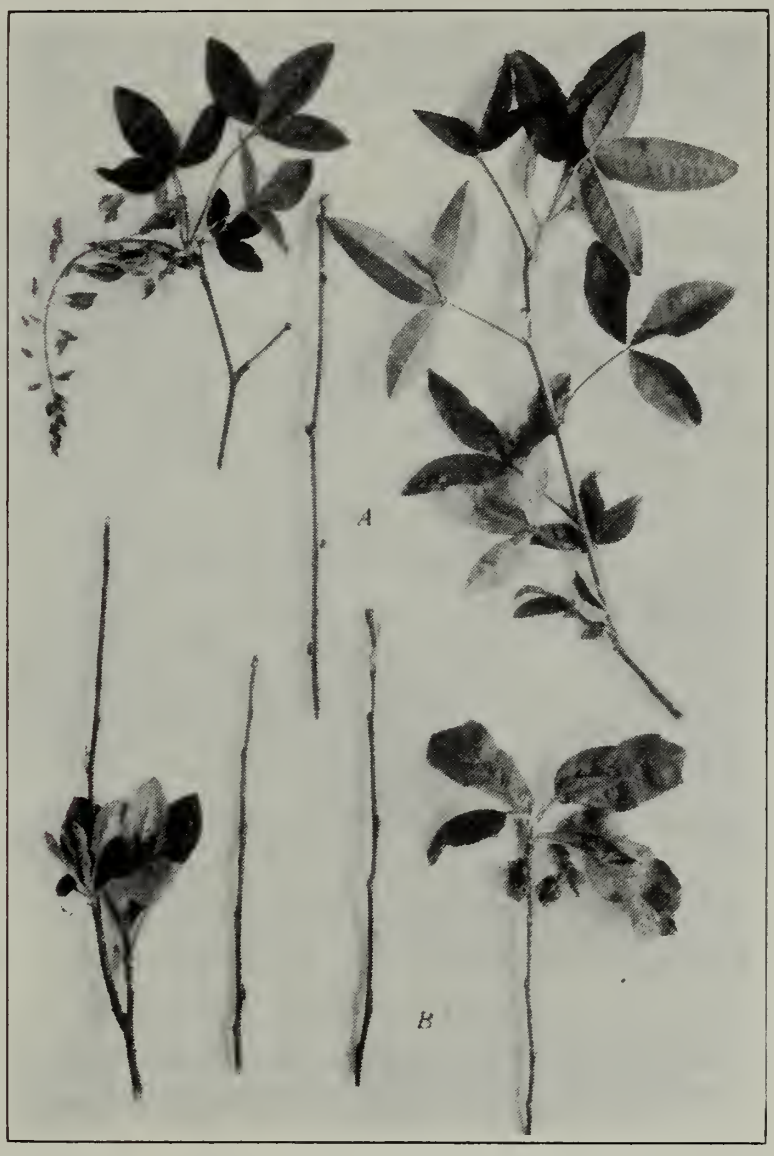

Fig 5.—*A*, Twigs taken from a tree of Vossi laburnum, one showing a shoot 8 inches long, another a cluster of flowers nearly fully open on April 10, when most of the buds on the tree were still dormant, like those on the twig in the center. *B*, Twigs from a Northern Spy apple tree on which leaves from some buds are nearly full grown more than a month before most of the other buds opened.

After especially warm winters, there may be a difference in time of opening even among buds on the same tree.[11] Buds on shoots that re-

[11] Denny, F. E., and Ernest N. Stanton. Localization of response of woody tissues to chemical treatments that break the rest period. Amer. Jour. Bot. 15(5):337–44. 1928.

mained succulent late in summer and grew to be several feet long may open as much as a month later than buds on shoots that ceased growth early and grew to be only 3 to 12 inches long. Even among twigs less than 12 inches long, there may be rather large differences in time of opening. For example, in figure 5, *A*, a bud on one laburnum twig after a warm winter produced a shoot about 8 inches long and another produced a flower cluster nearly full grown by April 10, yet most of the twigs on this tree were still dormant and some remained so for two months longer. Similarly, on a Northern Spy apple tree (fig. 5, *B*) after the same winter, a few buds opened early and produced nearly full-grown leaves before most of those on the tree had started breaking. On both the laburnum tree and the apple tree, some special influence, such as an injury, must have helped toward breaking the rest periods of the buds that started early. In sections where there is enough chilling weather to break the rest period of all buds completely, such starting of some buds long before others does not occur: once the weather is warm enough for growth, the trees come quickly into full blossom and full leaf.

Many studies have been made to determine what, in the chemistry of trees and other plants, causes the chilling requirement, but as yet no satisfactory information has been obtained.

PRACTICAL INFLUENCE OF THE CHILLING REQUIREMENT

Beneficial Effects of the Chilling Requirement.—In regions with longer, colder winters than those in any cultivated part of California, the benefit from the chilling requirement, or rest period, comes in autumn or early winter. Plants that survive such cold winters have what is known as a "hardening" or maturing process by which, before and after leaf fall, they gradually become much more resistant to freezing than they are at any time in summer, or than tropical plants can ever become. This hardening process cannot take place in any part of the tree when most of the shoots are growing. Yet there is usually weather favorable for rapid growth in late summer, in autumn, and, often, even in early winter. If the trees were not held dormant for satisfaction of the chilling requirement, in other words, if they were not in the rest period, they would usually be growing in late autumn and could not be prepared for early winter freezes. Some species, like the walnut, are slower to go into the rest period in summer than others, like the apple; they are therefore more apt to be growing in late summer and autumn and to remain tender in early winter. In fact, for this reason, walnut branches are often killed back in autumn or early winter even in California.

In regions like northern California, the benefit to the orchardist from the chilling requirement comes mainly in spring or in late winter. If lack of chilling delays the opening of buds to only a few weeks after the weather becomes warm enough for growth, that delay does not tend to reduce the crop but may actually increase it in some years. For when the chilling is not enough to release the buds completely, some are delayed in opening more than others, so that the blossoming period is longer and there is more time for satisfactory pollination. Further, the delay tends to cause blossoming to occur during better weather for pollination and setting.

The most important benefit is a reduction in the danger of losses from spring frosts: a moderate deficiency in winter chilling may delay open-

Fig. 6.—Cherry tree in a mountain orchard in Northern California, in full blossom under the snow on March 31, 1936, when the temperature fell to 20° F. (Courtesy of R. O. Davis.)

ing of the blossoms, and their becoming tender, until the time of killing frosts has passed. If the buds are completely out of the rest period when the first warm weather comes in early spring or late winter, they are apt to be exposed to killing frosts later, especially in the mountain districts (fig. 6).

Harmful Effects of Inadequate Chilling.—In some districts in some winters there is not nearly enough chilling for such kinds of trees as apples, pears, and peaches.[12] The flowers open so late, in such hot drying weather, that they are apt to fall without setting fruit.

[12] Weldon, G. P. Fifteen years' study of delayed foliation of deciduous fruit trees in southern California. California State Dept. Agr. Mo. Bul.23(7,8,9):160–81. 1934.

The fruit buds of some kinds, especially apricots, peaches, and plums, may fall instead of opening. In California this is the most widespread harmful effect of such warm winters. The apricot tree is more apt to shed its fruit buds than trees of other species, although the opening of its buds is not delayed so much by warm winters. In figure 7, *A, B,* are

Fig. 7.—*A, B,* The shedding of apricot fruit buds after a warm winter. Sometimes many of the blossoms that are delayed in opening after such winters also fall without setting fruit. *C, D,* Twigs of Lovell peach beginning to grow in spring after a winter too warm to break the rest period completely: *C,* one-year-old twig; *D,* two-year-old twig from the same tree.

shown two apricot twigs, each with one flower fully open and with many fruit buds just fallen off, or loose and ready to fall.

This loosening is due to the formation of a layer of cells, an abscission layer, that separates the bud from the twig. Abscission layers form normally before the falling of fruits, leaves, and flowers. When a fruit is injured, as by worms, or is ripe, when a leaf is injured or is old, when a flower is injured in some part, an abscission layer tends to form and

push it off. Likewise such an abscission layer may push off the fruit buds during warm weather when they have not had enough chilling. Just why it does so is not known. Maturity of the flower without pollination causes an abscission layer to be formed; possibly in warm winters some parts of the flower, such as the anthers that bear the pollen, become mature and stimulate abscission.

One or more leafy spurs or shoots, in addition to the flowers, grow from a fruit bud of the apple and pear. Sometimes during especially warm winters, the unexpanded flowers die in such a bud, but the shoot part either grows or remains alive in the bud; sometimes it remains alive but dormant for many years.

Leaf buds are not shed but may remain dormant throughout the summer. Sometimes all the buds on a twig remain dormant. In the next spring, unless the winter has been cold enough to break the rest period completely, such two-year-old buds (fig. 7, *D*) tend to start earlier than the normal, one-year-old buds (fig. 7, *C*). Or the two-year-old buds may grow and the one-year-old buds remain dormant. Of course, if the buds on many twigs fail to produce leafy shoots, there will not be enough foliage to support good growth of tree or fruit. If most of the buds fail to open, or are greatly delayed in opening, intensely hot weather may come before the branches are protected from the direct sun by foliage. On some trees, especially peach trees, branches are apt to be weakened or even killed by summer sunscald.

REMEDIES FOR TOO LITTLE CHILLING

No treatment of the trees to prevent losses after winters with too little chilling weather has yet been proved safe, completely effective, and inexpensive enough for commercial practice. The amount of delay in opening of the buds is influenced by treatments given the tree in the preceding year. For example, after a warm winter, trees that suffered for water in late summer and lost their leaves early may start shoot growth a little better and may blossom a little earlier. They are apt, however, to shed their fruit buds worse than trees that held their leaves late in autumn. Furthermore, the withholding of water in late summer would have to be practiced every year; for an orchardist cannot know in advance that a winter will be too warm. In most cases, if not in all, more harm than good will follow such withholding of water.

The pruning system used may have some influence on the opening of buds after a warm winter. The greatest delay is in buds on shoots several feet long, and severe pruning causes the growth of such shoots. Heading back to stubs in the top of the tree causes more long shoot growth than

cutting back to other branches. For some kinds of trees in some sections a system of pruning that causes such long, late shoot growth should probably be avoided. However, on some kinds, such as the apricot, although long shoots blossom and start growth later after warm winters, they do not shed their buds as badly as shorter shoots.

In South Africa,[13] spraying with an emulsion of raw linseed oil or of seal oil, during warm winters, is reported to have caused satisfactory growth and blossoming on trees of some kinds. The emulsion can be made by stirring vigorously 3 parts of water with 8 parts of oil, and soap enough to hold the oil in emulsion. Enough of this mixture is added to the water in the spray tank to make the spray contain 5 per cent oil.

Some of the oils used in winter spraying, especially lubricating oils of the western benzene series, tend to be about as effective as linseed oil and are cheaper.

The best results with any of these oils are obtained if the spraying is done after there has been some chilling weather. If it is done too early, say before Christmas in California, there may not be much effect. If it is done late, say too or three weeks before growth should start, it may actually delay starting. In South Africa, spraying about a month before growth normally starts is recommended. In northern California, blossoming and beginning of leaf growth are hastened most if the oil is applied about the first to the tenth of January. Most of the experience, however, has been in sections where there is usually a considerable amount of chilling weather in December. We have little knowledge for southern California, where there is less chilling weather before the first of January.

Sprays with other substances have been tried. At Watsonville, Ballard and Volck[14] found that spraying apple trees in winter with a pound of nitrate of soda to a gallon of water, with or without a little caustic potash, would sometimes hasten blossoming. In southern California, where the winters are considerably warmer than at Watsonville, trials indicate that the rest-breaking influence of this material is not strong enough to hasten blossoming measurably.

Spraying with solutions of ethylene dichloride, sodium thiocyanate, and thiourea, substances that have been used in the laboratory to break

[13] Black, M. W. Some physiological effects of oil sprays upon deciduous fruit trees. Jour. Pomol. and Hort. Sci. 14:175–202. 1936.

Mally, C. W. Raw linseed oil and seal oil for controlling irregular blossoming and foliation in fruit trees. South Africa Dept. Agr. Bul. 125 (Farmers' Bul. 72): 1–23. 1934.

[14] Ballard, W. S., and W. H. Volck. Winter spraying with solutions of nitrate of soda. Jour. Agr. Research 1:437–44. 1914.

the rest period of plants, has failed to hasten the opening of buds on peach and walnut trees after warm winters.[15]

Dinitro-o-cyclohexylphenol in oil used for dormant spraying hastened the opening of leaf buds on apricot trees in southern California in the spring of 1936, and hastened blossoming enough to cause the fruit to be ripe three or four weeks ahead of that on trees that were not sprayed

Fig. 8.—Winter Banana apple tree, photographed April 1, 1937. The right-hand side was sprayed on February 11, 1937, with 2 per cent oil containing 3 per cent dinitro-o-cyclohexylphenol; the left-hand side was not sprayed.

with this material.[16] The oil used contained 3 per cent of this material. The spray was 98 per cent water and 2 per cent of this treated oil.

In 1937, trials were made with this material on apricot trees and on trees with longer chilling requirements. Figure 8 shows the response of

[15] From unpublished work by D. G. Sorber and M. H. Kimball. These workers have used ethylene gas, also, to hasten the ending of the rest period of walnut, peach, and lilac trees. They obtained striking results when the trees were covered with tents and the ethylene released under them.

[16] The work with this material was begun by A. M. Boyce of the Division of Entomology in the Citrus Experiment Station at Riverside, California, in a study of insect control.

part of a Winter Banana apple tree in Los Angeles County. The right-hand side of the tree was sprayed on February 11, 1937. Its buds started earlier and more uniformly than those on the unsprayed side. The result seems striking when it is considered that trees had their chilling requirements more nearly completed during this winter than during any other since 1916–17. Results as striking were obtained on Seckel pear trees treated at the same time. Peach, apricot, sweet and sour cherry, Japanese plum, domestica plum, and even walnut buds opened earlier and more uniformly on trees sprayed during the first half of February with this material than on unsprayed trees. The influence was a little greater in Los Angeles County than at Berkeley, probably because the chilling requirement was more nearly satisfied at Berkeley.

When a 2 per cent emulsion of the oil alone was used, it seemed to cause the buds of some trees to open a little earlier than buds on unsprayed trees. The influence was slight, however, compared with that when the oil emulsion contained dinitro-o-cyclohexylphenol.

Spraying in winter with oil emulsions containing this material seems to be a more promising means of supplementing the chilling during winters that are too warm than any other that has been tried. There has not been nearly enough experience with it, however, to justify unqualified recommendation. So far, the only injury observed when it has been used at this low concentration was to a few peach trees, but we do not know that treatment followed by different weather would not be injurious to trees of other kinds.

In the present state of our knowledge, the most advisable precaution in sections with too little winter chilling is to choose varieties that have rather short chilling requirements and will blossom and start growth satisfactorily after warm winters.

WINTER CHILLING IN CALIFORNIA

These observations were begun in the spring of 1924, when, in some parts of southern California, the chilling requirement was brought strikingly to attention by a very injurious delay in opening of buds. In some deciduous orchards most of the fruit buds fell unopen and many opened late, in weather so hot that the flowers fell without setting fruit. On many peach trees, so few leaf buds grew that the branches were not shaded by foliage and were injured greatly by summer sunscald. There was injurious delay also in the springs of 1926, 1928, 1930, 1931, 1934, 1935, and 1936. By reference to figure 9, it may be seen that the winter preceding each of these springs was warmer than average. After colder winters in southern California, buds of most deciduous species did not

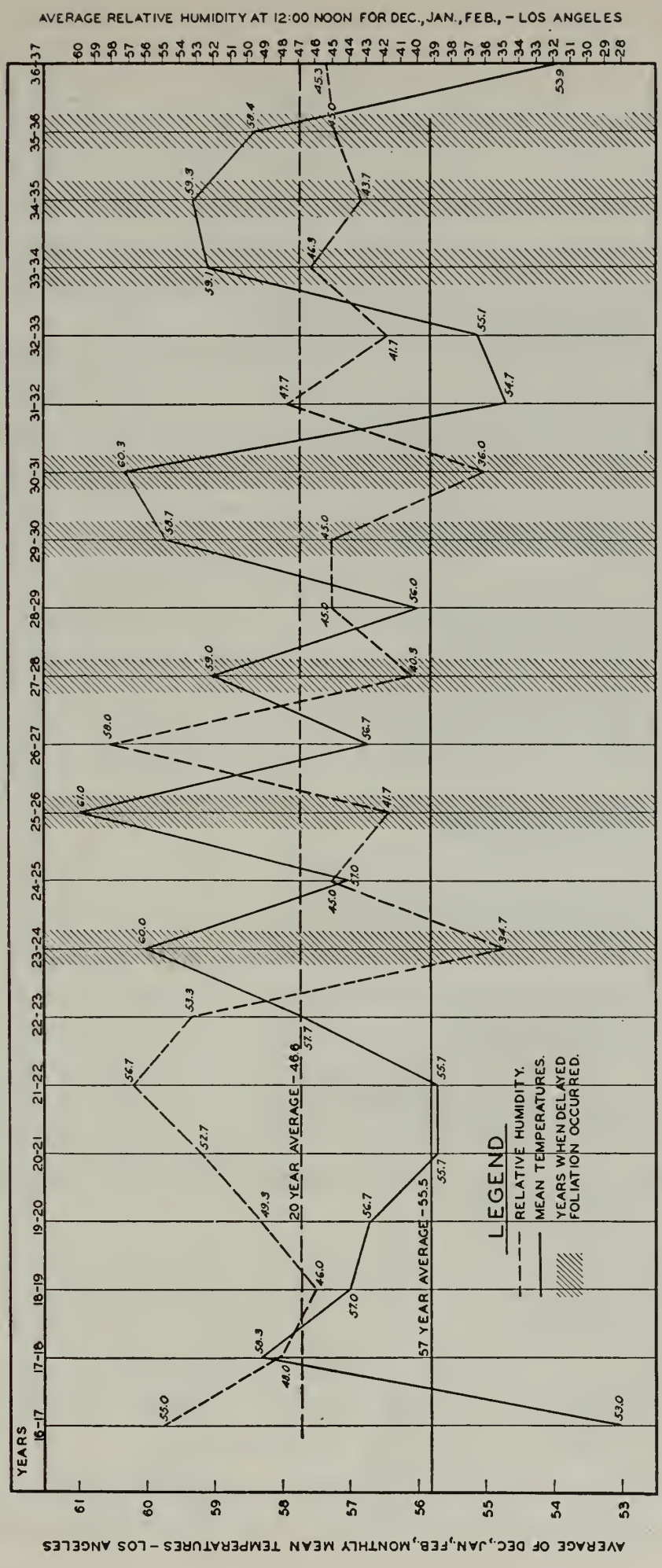

Fig. 9.—Average temperatures and humidity at noon, at Los Angeles, for the winter months from 1916–17 to 1936–37. The perpendicular bars mark the springs when, because of warm winters, there was injurious delay in opening of buds of deciduous fruit trees in parts of southern California. (Data from the United States Weather Bureau at Los Angeles.)

respond nearly so quickly as they would if the rest period had been completely broken; the delay, however, was not enough to be noticeably injurious. In fact, when opening of buds is said to be normal in southern California, what is meant is that the delay is not noticeably injurious.

Figure 9 shows that in southern California the winter of 1932–33 was a little colder than the average and that the next winter, 1933–34, was considerably warmer than the average. In figure 10, mean temperatures are shown graphically for these winters at a number of points in the state.

At San Diego, the exceptionally cold winter of 1932–33 was warmer than the exceptionally warm winter, 1933–34, at any of the other places. Probably the only deciduous-fruit varieties that could be grown there satisfactorily, except at high elevations, would be those with rather short chilling requirements. The mean temperatures for December and January, the important chilling months, were as high in the cold winter at Pomona as in the warm winter at Bakersfield and Modesto, in the San Joaquin Valley, or at Davis and Winters, in the Sacramento Valley. Usually, even after the coldest winters in a section as warm as Pomona, there is enough delay caused by incompleteness of chilling to make blossoming of the same variety later than in the San Joaquin or the Sacramento valleys. After the especially cold winter of 1936–37, this was true for most varieties of apples, pears, and cherries, also for some varieties of plums and walnuts.

Even in the San Joaquin and Sacramento valleys, from Marysville southward at least, there is not enough chilling in winter to completely break the rest period of some varieties of apples, pears, cherries, plums, and peaches. The buds do not open as nearly all together in spring as they would after longer, colder winters, and there is somewhat less leaf growth when the blossoms are open; the order of blossoming among different kinds and varieties also is influenced by the mild winters. For example, Bartlett is among the earliest varieties of pears to blossom in states with long, cold winters but among the latest in the San Joaquin and Sacramento valleys.

While this slight incompleteness of chilling influences the order of blossoming of the different kinds and varieties, its influence on the time of blossoming is less than the influence of differences in amount of heat in February and March. If these months are especially warm, blossoming of all kinds of fruits will be especially early, even after winters as warm as any observed at Davis during these fourteen years.

In most of California, in fact, the degree to which the chilling requirement has been satisfied and the amount of heat in spring are both influ-

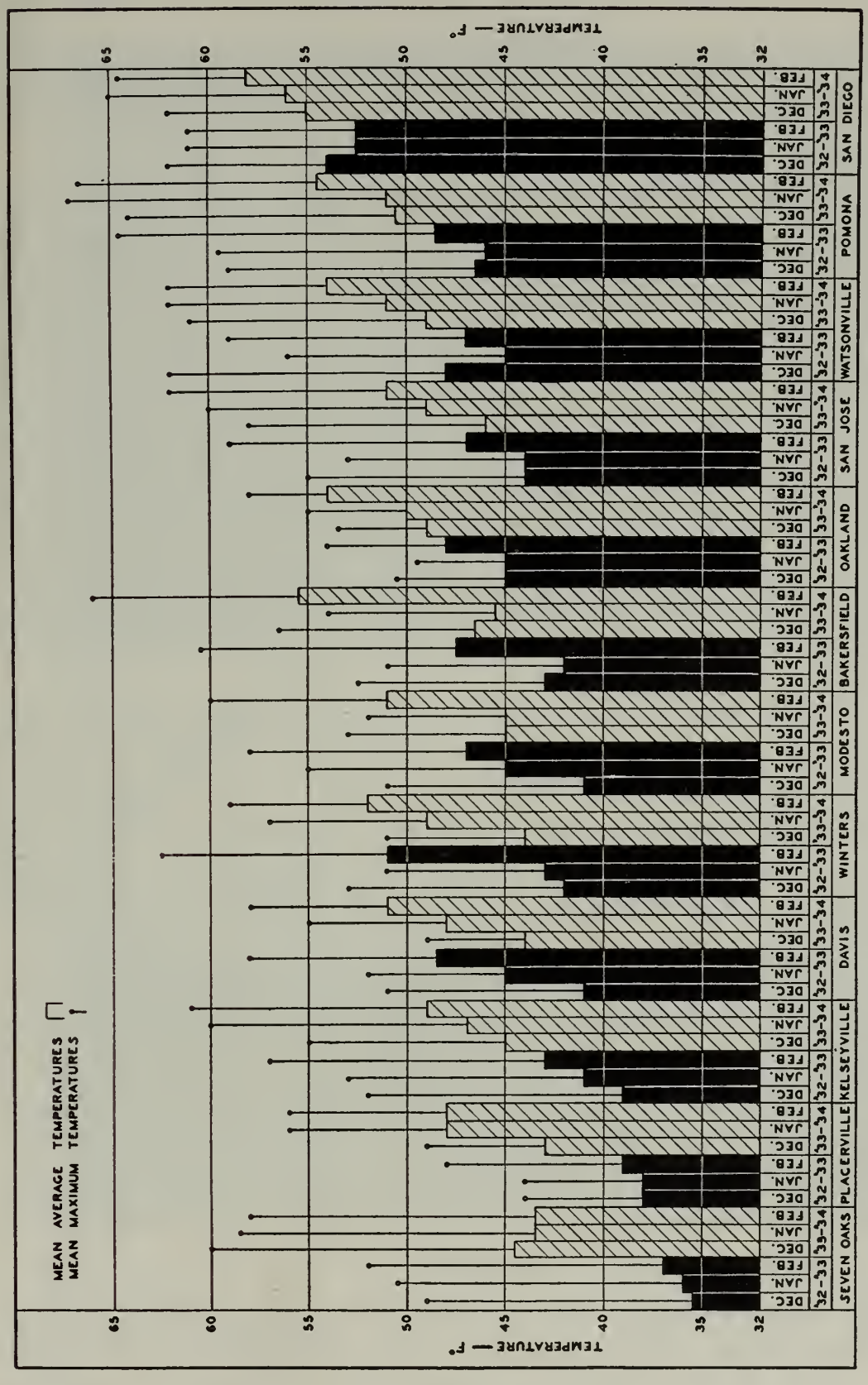

Fig. 10.—The black bars show the mean temperatures for December, January, and February, 1932–33; the white bars with diagonal black lines show the mean temperatures for the same months at the same places in 1933–34. The circles at the tops of lines extending from these bars indicate the average daily maximum temperatures for the same months.

ences that determine the time of blossoming and starting of growth. In the San Joaquin and Sacramento valleys, the amount of heat in spring is the stronger influence, while in parts of southern California, where the winters are warmer, the degree to which the chilling requirement has been satisfied tends to be the stronger. In other districts, where the winters are warmer than in the San Joaquin and Sacramento valleys but colder than those in southern California, the two influences are more nearly equal.

At Watsonville and Oakland, coastal positions, the mean temperatures for December and January, during the winters concerned in figure 10, were higher than at Bakersfield and Modesto, in the San Joaquin Valley. On the low ground at Watsonville and Oakland, there is rarely injurious delay in opening of buds of varieties with moderate chilling requirements such as Yellow Newtown apple and Elberta peach. Varieties such as the Mayflower peach that have especially long chilling requirements show more delay and more shedding of the buds than they would in the same winter in the San Joaquin and Sacramento valleys. On the higher land in or near Watsonville and Oakland, there tends to be less winter chilling weather than on low land, sometimes so little that there is rather injurious delay in opening of buds on varieties with moderate chilling requirements.

At Placerville (fig. 10) the winter of 1933–34 averaged a little colder than at Davis. Yet, although there was no injurious delay in opening of buds on Bartlett pear trees at Davis, there was both delay in opening of buds and dying of the unexpanded flowers in the buds in the Placerville area, except in shady places. In other words, the buds in clear sunlight at Placerville must have been kept warmer than those at Davis, during the daytime in winter.

Influence of Direct Sunlight.—When the sun shines directly on a colored object, its temperature gradually becomes higher than that of the air around it. The clearer and stiller the air, the greater the increase in temperature of a colored object will be. In dark-colored bark, temperatures more than 20° F above that of the air around it have been recorded.[17] Twigs in the shade have the temperature of the air. Shade may not affect the air temperature much, but it keeps twigs and buds cooler by excluding direct sunlight from them.

In California, therefore, trees in the shade have their chilling requirements satisfied better than trees in the sun. A good example of this phe-

[17] Whitten, J. C. Winter protection of the peach. Peach growing in Missouri. Missouri Agr. Exp. Sta. Bul. 38:140–64. 1897.

Mix, A. J. Sun-scald of fruit trees: a type of winter injury. New York Agr. Exp. Sta. (Cornell) Bul. 382:235–84. 1916.

nomenon is to be seen in spring on trees that were in the shade of tall windbreaks during warm winters in southern California. Because the sun is so low during the winter months, a tall eucalyptus windbreak on the south side of an orchard may cast a shadow over trees 140 feet away

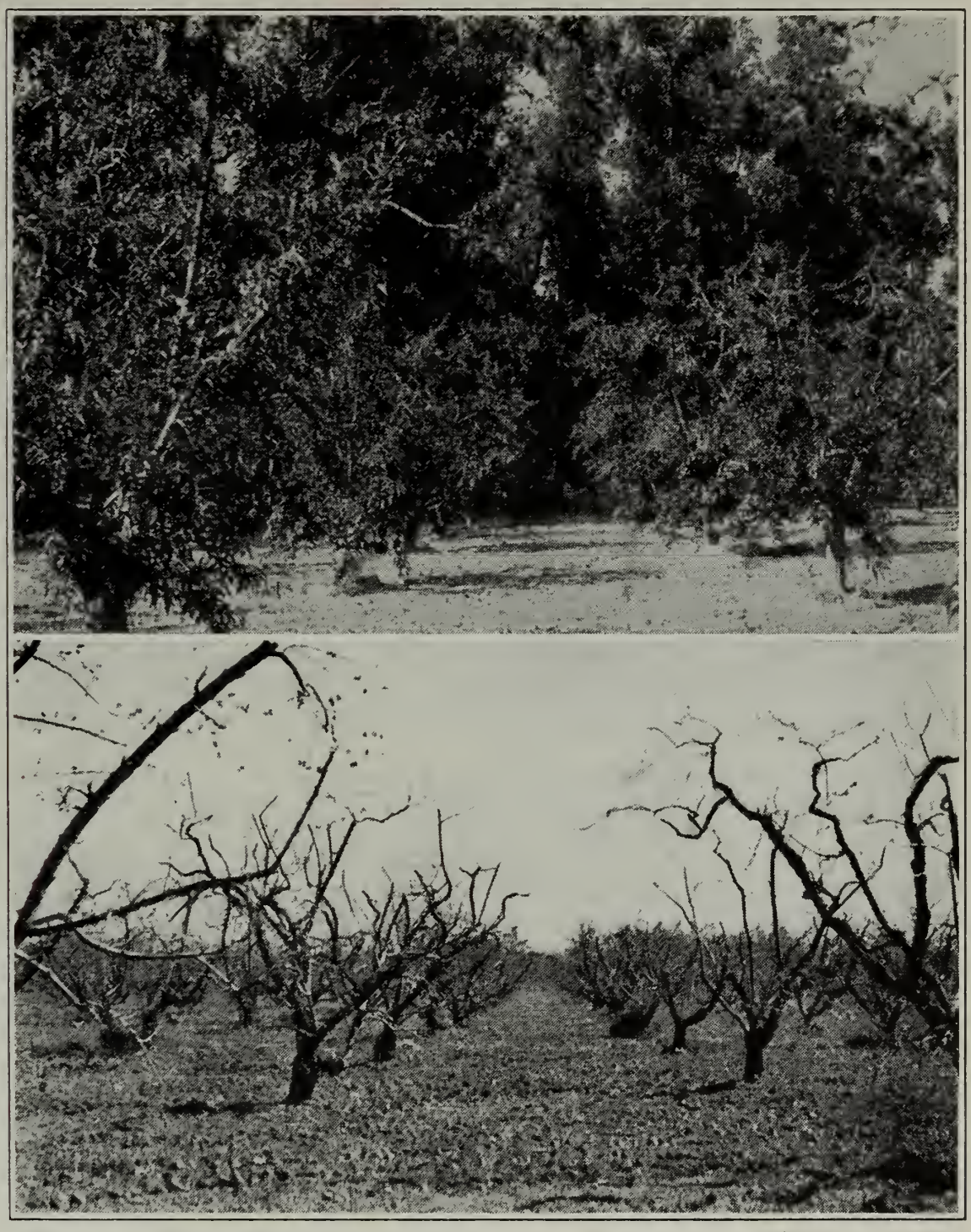

Fig. 11.—Elberta peach trees near Ontario, California, April 7, 1934. The upper ones, in full leaf, were in the shade of the eucalyptus hedge nearly all of each day during the winter months. The lower ones, in the same orchard, were not shaded during the winter, and only a few leaves have started to grow.

from it, at least until about 10 :30 a.m. and after about 1 :30 p.m. Buds on trees in its shadow during any part of the day in midwinter months will tend to open earlier than buds on unshaded trees (fig. 11). If only the

lower part of the tree was shaded, the buds on that part will start earlier than those that were in the sun all day. Buds on trees in the four or five rows next to the windbreak, rows that during the winter were shaded all day, will start a little earlier than buds on trees in the sixth or seventh row from the windbreak, rows that were shaded during most of the day but that were in the sun for a few hours at midday.

Buds on trees east of a windbreak, trees shaded in the afternoon, will open a little earlier than buds on trees west of a windbreak, trees shaded in the morning; this is because the sun is obscured by fog on many winter mornings and would not raise the temperature of twigs and buds even if there were no windbreak to shade them. Buds on trees against the north or east side of a building or trees on the north slope of a steep hill may start earlier than buds on unshaded trees.

In other words, after the warmest winters in southern California, the longer during each midwinter day a tree was in shade, or partial shade, the earlier its buds will start in spring, as compared with buds on neighboring trees that were not shaded at any time.

Winter Fogs.—The effect of winter fog is similar to that of shade: if it tends to obscure the sun during much of the day, it is very effective in breaking the rest period of plants; if it lasts only a little while during each foggy morning it is less effective but still causes trees to blossom and start growth a little earlier in springs after warm winters than trees in neighboring areas free from fog.

Tule fogs in the San Joaquin and Sacramento valleys are dense enough to obscure the sun later in the day, and are present in more days, than winter fogs in most other areas of the state. Foothill areas several thousand feet above these two valleys have little or no winter fog. Some such areas may have a mean winter temperature lower than that of the valleys and yet may not satisfy the chilling requirement as well. An example was the delayed starting of Bartlett pear buds and dying of some of their unexpanded flowers after the winter of 1933–34 in the Placerville district, latitude about 38.7°, elevation of from 3,000 to 3,500 feet (fig. 10, page 19). Such injury was observed in sunny positions from that district downward to the tule fog area in the Sacramento Valley, where none was found. Additional evidence that in this Placerville area delayed opening of the buds and dying of flower parts in them was due to absorption of heat from the direct sunlight was furnished by trees on steep north slopes or in other positions where they were shaded during parts of each winter day. In such positions blossoming was earlier than on unshaded trees and there was no dying of flower parts in the buds.

In the same spring, trees of several varieties of apples showed very

injurious delay at an elevation of about 5,000 feet at Oak Glen, in San Bernardino County, latitude about 34.3°. There were no temperature records at Oak Glen, but Seven Oaks in the same county has the same elevation and had lower mean temperatures for December and January than any other station in figure 10. Probably the mean temperature for the winter months at Oak Glen also was lower than at Modesto or Davis. Yet the delay in opening of buds was greater than at any points below the fog in the San Joaquin and Sacramento valleys.

The tule fogs in these valleys aid toward satisfying the chilling requirement not only by keeping the direct sun rays from raising the temperature of the buds above that of the air, but also by keeping the air temperature lower during the day. Figure 10 shows that the winters are somewhat colder at Davis than at Oakland. The differences would be greater if the temperature records at Oakland had been taken on the hills instead of the low ground.

Meteorologists[18] find that, in the San Joaquin and Sacramento valleys, the air which contains the fog is from polar maritime masses that have moved down from the north Pacific Ocean, perhaps from near the Aleutian Islands. This maritime air, after passing into these valleys, is held trapped by the mountains so that it does not mix readily with other air. It contains three or four times as much moisture as air from over the land. Moisture condenses in it, therefore, as soon as it is cooled a little. Radiation of heat from particles of dust and of moisture in this trapped air mass cools it further.

Polar continental air that settles downward from areas of high barometer in the mountains to the eastward, becoming warmer as it reaches lower elevations, remains over the trapped air in the valley, forming a ceiling of warmer, lighter air. It, therefore, may not raise the temperature in the valley conspicuously, although it reaches the earth and brings warm clear weather at Oakland and other coastal positions as well as at foothill positions around the valleys above the trapped air. In fact, the valley may become cooler: lying clear and dry over the trapped air in the San Joaquin and Sacramento valleys, this continental air provides excellent conditions for radiation of heat from the water and dust particles in the stagnant, moist air below. In this way the trapped air becomes cooler and the fog in it denser.

Thus, during warm, clear, winter weather in the San Francisco Bay area and in the hills around the great valleys, the fog in those valleys is apt to be at its densest and to be present nearly all day. Differences in

[18] Byers, Horace R., and Wilbur M. Lockhart. Characteristic weather phenomena of California. Mass. Inst. Technol. Meteorological Papers 1(2):1–54. Plates 1–22. 1931.

temperature between day and night and fluctuations from day to day are much less in this trapped maritime air in the valleys than in the clear winter air near the coast and in the foothills. The tule fog protects the earth from radiation so that the night temperature at the ground does not fall especially low. In brief, although the valley tule fog holds better chilling temperatures during the day and causes the buds to open satisfactorily in all springs, it does not increase the frost hazard. Rather, it delays the opening of the buds and their becoming tender in spring.

Trees in foggy areas in coastal districts are more apt to have their buds open satisfactorily after warm winters than trees in neighboring areas with little or no fog. These fogs are probably not all due to the same causes as those in the San Joaquin and Sacramento valleys. In most coastal areas there is fog in fewer days and it clears earlier in the day. In the Santa Clara Valley, however (San Jose in figure 10, page 19), chilling is about as satisfactory as in the San Joaquin and Sacramento valleys, except for some small areas that tend to have little fog.

SPECIAL CHILLING REQUIREMENTS OF FRUIT PLANTS

Opinions expressed in this section concerning special chilling requirements of some varieties will be based mainly on observations in the different parts of the state during the last fourteen years. Concerning a few varieties that were not found in the best locations for observation, opinions will be based on reports from South Africa.[19] The most detailed observations in California were made (1) at Davis; (2) in Berkeley, both on low ground and on hillsides; and (3) in southern California, both in sections with some winter fogs or coolness caused by elevation and in the warmest sections.

At Davis, chilling is so nearly adequate in all winters that differences in time of opening of buds are due largely to differences in the amount of warm weather for growth in late February and March. Trees of most kinds will blossom and start growth before March 15 if late February and March are especially warm and will be delayed until late March and early April if late February and March are especially cold.

At Berkeley, even on low ground, the winter nights are a little warmer and the winter fogs clear a little earlier in the day than at Davis. In most winters there is not much weather too cold for some growth by many plants. Lemon and redwood trees are apt to be growing nearly all winter. In the coldest parts of some winters, it is warm enough for decid-

[19] Reinecke, O. S. H. Die-back of fruit trees in the Western Cape Province. South Africa Dept. Agr. Bul. 97 (Farmers' Bul. 34):1–16. 1931.

uous trees to be growing if they were not in the rest period. For example, an apple tree put back in the orchard December 23, 1930, after having been in cold storage long enough to break the rest period, had leaves nearly a half inch long by January 20. The springs become warm earlier at Berkeley than at Davis, so that trees like the almond, which have very slight chilling requirements, start earlier, although trees like the apple, which have long chilling requirements, start later than at Davis. In the parts of Berkeley above the winter fogs, nights are warmer than in lower parts or than in Oakland (fig. 10, page 19), and there is more sunshine to raise the daytime temperatures of the buds above that of the air. Sometimes the difference in spring behavior of trees that were under the winter fogs and trees just above those fogs is very striking. For example, Bartlett pear or Delicious apple trees that were below the winter fogs may start growth moderately well after the warmer winters, while less than a mile away on a hillside above the winter fogs, buds on trees of these varieties open in a much more straggling way, some as late as September, most of them remaining dormant throughout the year.

In nearly all of southern California except at high elevations, trees of such kinds as the orange and the lemon make more growth in winter than in the warmest parts of Berkeley; and trees of such kinds as the apple start later in spring because of the warm winters.

While observations in these areas have given much information concerning the behavior of trees of different species and varieties after warm and cooler winters, it is not yet possible to place all of them exactly with reference to the amount of chilling winter weather required for satisfactory opening of the buds in spring. The nature of the chilling period—whether its days that are warmer than normal come early or late—may influence the trees of some species or varieties differently from those of others. Or, the best chilling temperature may be a little lower for some species and varieties than for others. Whatever the explanation may be, the amount of delay in blossoming and in starting of growth is not always in the same order for the different species, or for varieties of a species, after different warm winters. What will be said about kinds and varieties has tended to be true during the period of observation in California.

FIGS AND PERSIMMONS

The fig and the Oriental persimmon, *Diospyros kaki,* are examples of deciduous trees with chilling requirements so slight that they can be grown satisfactorily in the parts of California where the winters are the warmest.

It seems probable that they have at least a slight rest period, for they usually remain dormant through favorable conditions for growth in autumn and early winter. In fact, after the warmest winters in the warmest sections of southern California, they show a slightly uneven starting of buds on the trees, as they would if there was not enough chilling to break the rest period completely. They are reported to show this tendency even more in southern Florida. Any chilling requirement they have, however, is so slight that they start growth earlier in southern California than at Davis; and in the parts of Berkeley where the winters are warmest, all buds open together, early. Such evidence of a rest period as they show is a little stronger for the Oriental persimmon than for varieties of figs grown in southern California, but there is no part of the state in which the winter is too warm for satisfactory spring growth of either.

The American persimmon, *Diospyros virginiana,* has a chilling requirement long enough to cause some delay in Berkeley, and rather serious delay, with uneven starting of the buds, after the warmest winters in southern California. The variety Miller shows more of such injury than Early Golden or Ruby.

POME FRUITS

Apples.—The average variety of apples requires more chilling before all its buds will open together in spring than the average varieties of most other kinds of fruit trees. If there is not at least two months during which the temperature averages below 48° F, opening of the buds in spring will be considerably delayed and some will open long before others. There is, of course, late blossoming that is not due to lack of chilling. Such abnormal clusters as *B* in figure 12 tend to open six to eight weeks after normal blossoms, even on a tree that has been adequately chilled, but normal, short-stemmed clusters like *A* in figure 12 open so late only after winters too warm to break the rest period of the buds.

In most of southern California, except at elevations well above 2,000 feet, this long chilling requirement tends to make apple growing unsatisfactory: in fact, it has caused the apple industry to be discontinued in some rather large districts. Above the winter fog line in Berkeley and Oakland, after the warmest winters, only a few varieties will open early enough to set a fair crop of fruit, and the buds of some varieties may open in a straggling way from March to September, many remaining dormant until the next year, or permanently.

In the leading apple-growing districts (around Watsonville and Sebastopol), although there is less chilling than in most of the Sacramento

Valley, there is enough during nearly every winter to cause satisfactory opening of the buds of the varieties grown; the yields, on good soil, are very high.

There is difficulty in spraying for codling moth in apple orchards after winters warm enough to cause the buds to open unevenly, since some blossoms are ready for the calyx spray long before others are open. In Berkeley, as in South Africa, spraying in late January with linseed oil, or with the lubricating oils used for insect control, has caused the

Fig. 12.—*A*, Normal twig-terminal blossom cluster of Red Canada apple, just open on July 22, 1930, after a warm winter, above the winter fogs in Berkeley; *B*, abnormal cluster at the end of a rather long, leafy shoot.

buds to open earlier and more nearly all together. Spraying with 2 per cent of oil containing 3 per cent of dinitro-o-cyclohexylphenol (that is, 0.06 per cent in the spray) seemed more effective than any oil alone, both in Berkeley and in southern California in the rather cold winter of 1936–37. It has not yet been determined, however, whether or not the influence of this material or of oil sprays is strong enough to cause uniform blossoming in sections of southern California after warmer winters.

Crab-apple trees of varieties such as Hyslop, Transcendent, Whitney, Yellow Siberian, and Red Siberian, which are hybrids between the true

Siberian crab, *Malus baccata*, and the common apples, will blossom and start growth well after winters considerably too warm for trees of most common apple varieties, although a few varieties of common apples start nearly as well.

Hume, Wealthy, Early McIntosh, Winter Banana, White Winter Pearmain, and Wolf River, seem to blossom and set fairly good crops after winters only a little colder than most of those in southern California. Rhode Island Greening, Yellow Newtown, and Yellow Bellflower usually require somewhat more chilling for the buds to open as well; Delicious, Golden Delicious, Jonathan, Gravenstein, and Cox Orange Pippin, a little more than Yellow Newtown; Winesap, Red June, and Red Astrachan, still more; McIntosh and Wagener still more; while Rome Beauty, Macoun, Red Canada, Twenty Ounce, and Northern Spy require, for good growth and yields, the most chilling of all varieties that have been under observation in California.

A leaf bud of the apple is quick to go into the rest period in summer, if its shoot stops growing. If an apple tree suffers for water during a few weeks it tends to stop growing and go into the rest period so deeply that it cannot make more shoot growth in the same summer. This is apt to occur even if the water deficit comes in early summer and to young, vigorous trees. It would require a longer water deficit for trees of some other fruits, such as the apricot, to be thrown completely into the rest period.

Pears.—Winters that are too warm cause problems with pear trees similar to those with apple trees: uneven opening of the blossoms causes the same difficulty in spraying for codling moth; flower buds greatly delayed in opening have the same tendency not to set fruit; and there is on pears the same tendency as on apples for many leaf buds to remain dormant throughout the summer after an especially warm winter and, therefore, for total growth and possible yield to be reduced through the reduction in leaf surface. The flowers seem more apt to die in the buds on pear trees—Bartlett pear trees at least—than on trees of varieties of apples that have been observed. Spraying in early January with linseed oil, seal oil, lubricating oil, or dinitro-o-cyclohexylphenol in oil, seems to be as effective in promoting early opening of buds after warm winters with pears as with apples.

Because of its long chilling requirement, the Bartlett pear blossoms later than peach varieties even in the Sacramento Valley, though in the northern states, after their long winters, it tends to blossom earlier.

In the Sacramento, Santa Clara, and Antelope valleys, delayed starting in spring from lack of winter chilling seems rarely, if ever, to be a

direct cause of reduced growth or yield by Bartlett, or other varieties. This is true also in all but a very small percentage of the years in the fog-free foothill districts around the Sacramento Valley. In fact, because of its late starting, Bartlett is considered a good variety to grow in some foothill situations where the nights are too frosty for peaches and plums.

There are, however, two ways in which the long chilling requirement of the Bartlett pear may occasionally cause growers losses even in northern California. First, the cost of controlling pear blight may be increased a little. Insufficient winter chilling delays the opening of some buds so much more than others that the blossoming period is prolonged

Fig. 13.—*A*, Winter Nelis pear tree almost in full leaf, blossoms fallen; *B*, Bartlett tree with buds just opening, at Davis in the spring of 1935, after an especially warm winter.

and there is more time for fire blight to be spread through the flowers. Further, the longer the blossoming period, the greater the probability that during it there will come a spell of humid weather favorable for the growth of the fire-blight organism in the flowers.

Second, in springs after especially warm winters, it may reduce the effectiveness of cross-pollination, in districts where this is needed. If the rest period is completely broken before spring, Bartlett blossoms earlier than Winter Nelis. This seldom or never happens in California, but after the coldest or foggiest winters in the Sacramento Valley it may blossom as early as Winter Nelis, as early also as other varieties, such as Comice

and Hardy, that may be grown to pollinize it. After most winters in this valley its blossoming begins a little later than that of these varieties but not too late for fairly satisfactory cross-pollination. After the warmest winters, however, its blossoming may not begin until after that of Winter Nelis is completed (fig. 13).

In the warmest parts of southern California after the warmest winters, Bartlett pear trees blossom and start growth in a straggling way and do not set fruit well, certainly not so well as White Winter Pearmain apple, apparently not so well as Yellow Newtown, and not much better than Rome Beauty.

A considerable number of varieties of the common pear have been observed in Berkeley on the low ground and up the hillsides above the winter fogs. Beginning with those that have the shortest chilling requirements, and that therefore tend to blossom earliest after especially warm winters, they are in about the following order: P. Barry, Forelle, Flemish Beauty, Anjou, Clairgeau, Louise, Dana Hovey, Seckel, Louis Pasteur, Winter Nelis, Duhamel, Comice, Superfin, La Favorite, Bosc, Hardy, Elizabeth, Packham Choice, Marguerite Marillat, Frederick Clapp, Bartlett, Gorham.

In sections having as much winter chilling as Berkeley but warmer springs, this order of blossoming after warm winters may not be due entirely to the chilling requirements. P. Barry and Forelle, for example, will start growth and open the flowers at lower temperatures than most of the others require. Their earlier blossoming after rather warm winters is due in part to short chilling requirements and in part to their growing at lower temperatures than the others. Although Forelle starts early in Berkeley, it gives evidence by straggling opening of leaf buds, even of the leaves in the fruit buds, that it is starting against a considerable amount of rest-period influence that is holding it back.

Gorham, an excellent new variety, shows considerably more delay in starting than Bartlett after the warm winters in Berkeley. In fact, there is rarely a winter cool enough to cause the buds of this variety to open satisfactorily in Berkeley. Even in the Santa Clara Valley, it has shown some injurious delay in starting. It seems suitable in California only for those pear-growing districts with the longest, coldest winters. Some other Bartlettlike seedlings also have been tried and found unsuited to the parts of the state where the winters are as warm as those in Berkeley.

The Oriental or Japanese pear, *Pyrus serotina,* formerly used extensively as a stock for other pears, does not require as much chilling weather before it will start normally in spring as P. Barry, Forelle, or Flemish Beauty. This is true also of varieties such as Kieffer, Garber,

and LeConte, hybrids between the Oriental pear and the common pear. These will start reasonably well in spring after the warmest winters in southern California.

Like the apple, buds on trees of most varieties of the common pear go into the rest period rather quickly after growth is checked in summer, and hence a second cycle of shoot growth in the same summer is not frequently seen.

Quinces.—(For Chinese and Japanese quinces see pp. 51, 52.) Buds of the common quince, *Cydonia oblonga,* do not require much chilling and will open, nearly all together, after any winter in any district in California. The quince is the last of the fruit trees to blossom in sections where the winters are long and the chilling requirements of all kinds are completely satisfied before weather warm enough for growth begins. This is because the flower is at the end of a leafy shoot that must have time to develop before the flower can open. In California with its warm winters, however, the quince tends to make all this growth and get its blossoms open before apples and Bartlett pears, even in the Sacramento Valley. After the warmest winters, it tends to blossom before other varieties of pears, as well as before most varieties of peaches, of European plums, and of cherries.

STONE FRUITS

Peaches and Nectarines.—There are several groups of peach varieties with different chilling requirements. The largest, which includes nearly all well-known peach varieties grown in America, will be called "common" peaches in this paper.

Most varieties of common peaches, and of nectarines, tend to have slightly shorter chilling requirements than the average variety of apples: if the winter is barely too warm for apple buds to open uniformly enough and early enough to set a full crop of fruit, common peach buds and nectarine buds may open satisfactorily and the trees may not have their crops reduced at all by the warm winter; this tends to be true at Yucaipa, in southern California. Still less chilling, however, may injure peach trees more than apple trees, and reduce their crops more; this tends to be true, after the warmest winters, at Ontario and in other districts in southern California.

In the experiments that have been reported, peach and nectarine trees have shown less response than others to oil sprays given early in January of warm winters. They seem, however, to respond as well as any kinds of trees to spraying with 2 per cent of oil containing 3 per cent of dinitro-o-cyclohexylphenol (that is, 0.06 per cent in the spray).

Next to the apricot, the common peach tree is most apt to shed its fruit buds, unopened, during or after warm winters. Many of the flowers that open do not expand to full size before they fall and others fall after reaching full size. This is especially true of J. H. Hale and Phillips Cling. Furthermore, some of the fruit that sets is small and woody like that shown in figure 14. It may soon shrivel and fall.

If the winter is very warm, a larger percentage of the leaf buds remain dormant throughout the following summer on peach trees than on most other kinds of trees. Sometimes, after the warmest winters, the

Fig. 14.—Phillips Cling peach branches taken at Ontario June 15, 1931. On all but one, the terminal bud failed to grow; and all but two lateral leaf buds failed. Some of the flowers set fruit, but most of it apparently was not pollinated and is shriveled, ready to fall.

only shoots to grow are from buds in old wood, buds that failed to grow in preceding years. In figure 14 are shown six twigs that grew in 1930, on which only 3 out of at least 33 leaf buds grew in 1931. The others remained dormant until 1932, when many of them started early as shown in figure 7, *D*, page 12. In summers after such warm winters, there seems to be more damage to the wood from sunscald on common peach and nectarine trees than on other trees.

Of all the varieties observed in California, Mayflower seems to require the most chilling before its buds will open normally, and it seems to shed its fruit the worst. It is followed closely, however, by Briggs Red May

(Briggs), Hale Early, Sneed, and Alexander, and these are followed closely by Phillips Cling, Triumph, Champion, Muir, and Strawberry.

Elberta, Lovell, Tuscan (Tuskena), Peak, Paloro, Peregrine, and most of the nectarine varieties seem to be about median in their chilling requirements. J. H. Hale leaf buds start about as well as Elberta after warm winters, but it does not set nearly as good crops. Stanwick nectarine has its blossoming delayed a little more than the others by warm winters, but it does not shed its buds badly and tends to set good crops after rather warm winters. In some districts of California after the warmest winters, however, trees of all these varieties may make only a sparse growth and be badly damaged by sunscald, and may shed most of their fruit buds or their blossoms, setting little or no fruit.

Among the early-ripening common peach varieties grown in California, Vainqueur and Early Imperial, of varieties grown for fresh fruit, and Sims, of varieties for canning, seem to be the most resistant to warm winters. Hiley is not grown in California but is said to fruit better than other good market varieties after the warmest winters in southern Georgia.

In the San Joaquin, Sacramento, and Santa Clara valleys, and in northern foothill districts, there is not much loss in peach orchards. In some years, trees of Mayflower and a few other unimportant early varieties may shed too many fruit buds; and in 1935 the Phillips Cling crop was reduced somewhat from the same cause. Usually in these areas, however, the delay in blossoming after winters when the chilling requirement is not completely satisfied is not enough to be harmful but only enough to cause the frost hazard to be somewhat less than it would be if they could open, like almond buds, whenever there is enough warm weather after the first few weeks of winter. Because of this moderate delay and because peach flowers if uninjured tend to set fruit so dependably, the annual peach crop in these valleys is about as uniform from year to year as any crop known, perhaps more uniform than even corn or wheat.

There are groups of peach varieties with shorter chilling requirements than common peaches have. One is known as Spanish or Indian peaches, from trees brought by the early Spanish settlers (fig. 15). Others are from the varieties Honey and Peen-to, both from south China. Honey fruits are oblong, conic, beaked. The buds require a little more chilling than almond buds. Peen-to fruits are depressed at the blossom and the stem ends so that the form suggests the name saucer peaches, sometimes applied to them. The buds do not require more chilling than almond buds, if as much.

Neither Honey nor Peen-to is desirable for the market, but both are promising for crossing with common varieties to obtain good market varieties with short chilling requirements. Two such varieties from crosses made by Professor E. B. Babcock, named and introduced by others[20] as Babcock, and C. O. Smith, seem entirely dependable, after the warmest winters in southern California, and have good color and quality. In northern California they would have a little greater frost hazard than the common varieties have, but for southern California they seem

Fig. 15.—Amount of growth made on trees of different varieties of peaches by April 13, 1934, after an especially warm winter at Ontario: *A*, tree from a cross made by Weldon between Sims and a tree of the Spanish type; *B*, tree of Peak, a common peach variety.

promising. Many seedlings, obtained by crossing common peach varieties with varieties having shorter chilling requirements, are being grown by different workers. It seems reasonable to expect that for each ripening season there will eventually be at least one good market variety that blossoms well after warm winters.

Almonds.—Buds of the almond seem to require a little chilling before they will open in the orchard, but that supplied in December and the first half of January in Berkeley is enough to cause the blossoms to open, those of the same variety nearly all together, late in January or early in February. At Davis, in the Sacramento Valley, because January weather tends to be too cold for growth, the earliest blossoming varieties tend to be a little later than at coastal positions like Berkeley, and there is more difference in time of blossoming of different varieties. This is because of

[20] Weldon, Geo. P., and J. W. Lesley. The Babcock peach. California Agr. Exp. Sta. Circ. 328:1–5. 1933. (Out of print.)

differences in temperature requirements: the weather may be warm enough by late January or early February for blossoming of some varieties but not until a month or six weeks later for blossoming of others. In other words, the long period of blossoming in an almond orchard of mixed varieties in the Sacramento Valley is due in part to the fact that the rest period is broken by midwinter and in part to a considerable difference among varieties in temperature requirements for growth of the fruit buds.

In the warmest parts of southern California, after the warmest winters, they tend to start a little later than at Berkeley, and the opening is a little straggling. This fact suggests that sometimes in southern California such chilling requirement as almond buds have may not have been satisfied completely enough for unhindered opening. This slight delay does not seem to reduce growth or yield of the trees appreciably.

Although the almond seems to require some chilling before its buds will open normally, nearly all together, the amount is so slight that it can be replaced as early as December by influences too weak to cause apple, pear, or peach buds to open so early. For example, if almond twigs are cut early in December, before they have been subjected to an appreciable amount of chilling, and are placed with their bases in water in a warm room, leaf buds and fruit buds on them will open.[21] Apparently the mild influence of wounds at their bases is enough to replace their slight chilling requirement. Buds on twigs of most deciduous fruits would require another month of chilling before they would start when cut and placed in a warm room.

Apricots.—Leaf buds of the apricot, and fruit buds that remain on the tree, require less chilling weather to enable them to open by the first of March than do buds of most varieties of apples, pears, peaches, European plums, or cherries. After rather warm winters at Davis, however, earlier opening of the buds on the lower, weaker twigs of a tree, as in figure 16, shows that the rest period is not completely broken by spring. The delay on the long twigs after warm winters is much greater in southern California: fruit is sometimes more than ½ inch in diameter and leaves full grown on lower twigs or spurs when the buds are just opening on twigs several feet long. Yet even in the south insufficient chilling rarely prevents the eventual opening of enough leaf buds on apricot trees to cover them well with foliage.

Unevenness in opening of buds on a tree or on different trees in the same neighborhood is not always associated with differences in length of

[21] Hodgson, Frank R. Observations on the rest period of deciduous fruit trees in a mild climate. Amer. Soc. Hort. Sci. Proc. 20(1923):151–55. 1924.

twigs; some other influence during the preceding summer must have affected the chilling requirement of the buds from which the fruits in figure 17 grew.

In Berkeley, in spite of the warmer Decembers and Januaries, apricots tend to blossom and start growth a little earlier than at Davis, because it tends to be warmer in February at Berkeley. But in southern California, where Decembers, Januaries, and Februaries are warmer

Fig. 16.—Tilton apricot tree photographed at Davis, March 30, 1930, after an exceptionally warm winter for that area. Blossoms are barely open and leaf buds just breaking on the long twigs in the upper part of the tree. Blossoms have fallen and leaves are nearly full grown on the shorter, weaker twigs in the lower part of the tree.

than at Berkeley, the apricot tends to blossom later than at Davis, especially after the warmest winters. In other words, lack of winter chilling is apt to be the dominating influence in determining the time of blossoming and the starting of growth in southern California, but not in northern California: lack of winter chilling influences the time of starting

somewhat in northern California, but the amount of heat after the rest period is partially broken by chilling has the greater influence.

If it were not for the shedding of fruit buds, as shown in figure 7, *A* and *B,* page 12, the warm winters in the warmest parts of California would not prevent the production of at least fairly good apricot crops. Because of the stronger tendency of the trees to shed many of their fruit buds after warm weather, however, losses from lack of chilling in apricot orchards are probably greater for the state as a whole than losses from this cause in orchards of any other kind. Even in the San Joaquin, Sac-

Fig. 17.—Twigs taken from Royal apricot trees on March 30, 1930, at Winters, in northern California, showing variation in size of fruit. This variation was caused by greater delay in opening of some buds than of others after a warm winter.

ramento, and Santa Clara valleys, if there is more than the normal amount of warm, sunny weather in December and January, many of the fruit buds will remain unopened at blossoming time and soon fall off. This shedding of buds may sometimes be due to other causes, but most of it seems to be due to warm winters.

Trees in shallow, poorly drained, or too gravelly soils, trees that were not pruned enough, trees that did not have enough nitrogen, or trees that suffered for water in the preceding summer, are more apt to shed

their buds after warm winters than vigorous trees that had good care in all details during the preceding summer. This is true in spite of the fact that blossoming and starting of growth are delayed more on strong shoots of vigorous trees than on weak trees.

Spraying with oil early in January will hasten blossoming and starting of growth after the warm winters. It does not, however, seem to prevent the shedding of the fruit buds. On the other hand, in the spring of 1937, in one orchard in southern California, there was serious shedding of the fruit buds on all the trees except those sprayed with 2 per cent of oil containing 3 per cent of dinitro-o-cyclohexylphenol (that is, 0.06 per cent in the spray). This effect, however, may have been due to some other influence of this material on the buds than a hastening of the end of the rest period: the only warm winter weather was in December and the spraying was not done until early in February.

If this new phenol compound does not prove generally effective, the only methods now available for reducing the losses from shedding of the fruit buds after warm winters are to grow apricots only on good land, to practice good soil management, and to give them moderately severe pruning, enough to keep the leaves green and firmly attached until warm autumn weather ceases but not enough to cause the growth of many shoots 3 to 5 feet long. The only method more effective than this, for orchards of the future, seems to be to obtain by breeding good market varieties that will not shed their fruit buds.

Of varieties well known in California, Newcastle, a variety not widely satisfactory for the market, seems generally to hold its fruit buds best after warm winters, with Blenheim and Royal next. Tilton, Moorpark, and Hemskirke shed their buds worse than Royal after most warm winters, but in 1935–36 the cold weather in February seems to have come in time to prevent shedding on these but not in time to prevent it on Blenheim and Royal. The Russian apricot varieties, such as Shense, shed so many of their buds that they almost never set any fruit, even after the rather good chilling at Davis.

Common, or Domestica, Plums and Prunes.—The common plums, *Prunus domestica,* which came to us through Europe from their native home in western Asia, are sometimes called European plums. They include, besides all the prunes, such varieties as Jefferson, Washington, Yellow Egg, Diamond, Pond (erroneously called Hungarian), and President. The varieties in this group are highly variable in their chilling requirements. Some, such as President, Diamond, and French prune (Agen), are at least equal to such peach varieties as Elberta and Paloro in chilling requirement; others, such as Tragedy and Sugar prune, are

able to blossom and start growth satisfactorily after any but the warmest winters in southern California.

After warm winters in northern California, trees of French prune and other domestica varieties with rather long chilling requirements will blossom and start growth earlier if they have been sprayed with oil early in January. The spraying is usually not necessary for a good crop, however. Spring weather tends to have more influence than winter weather upon the amount of fruit set in these northern sections.

Trees of the best-known varieties of domestica plums do not tend to shed their buds as badly as apricot trees. But if winters are warm enough to cause blossoming to be very late, usually not much fruit will set.

Damson Plums.—There are a number of varieties of plums in the Damson group. Some of them have chilling requirements so long that they will rarely start growth and blossom normally on the hills above the winter fogs in Berkeley. Others will start reasonably well in spring even in southern California. In ordering Damson trees, a grower cannot be certain which variety he will obtain unless he has seen trees from the same nursery starting after warm winters. A tree that does not start satisfactorily after a warm winter can, of course, be top-worked to a strain of Damson that does.

Oriental (Japanese) Plums.—Most of the varieties of Japanese plums, *Prunus salicina,* have only moderate chilling requirements. Opening of their buds, however, may be delayed and uneven after warm winters: after the warmest winters in southern California there may be blossoms on the longest twigs and fruit ½ inch in diameter on short twigs of the same tree. Even after the exceptionally cool winter of 1936–37, opening of the buds on some Japanese plum varieties in Los Angeles County was hastened by spraying with 2 per cent of oil containing 3 per cent of dinitro-o-cyclohexylphenol (that is, 0.06 per cent in the spray). The hastening was not necessary for good growth and blossoming, however. In some years, in spite of this delay in starting of many buds, enough fruit will set for a good crop, though the time of ripening will be late. In most years enough leaf buds grow to support a good crop. After especially warm winters, blossoming may be too late for a crop to set on trees of a few varieties, such as Climax and Burbank, and there may be losses from shedding of the buds of these and other varieties such as Beauty and Santa Rosa. This was true in the winter of 1935–36 even in some foothill areas of the Sacramento Valley. Trees of leading varieties of these Japanese plums, such as Beauty, Santa Rosa, Wickson, and Kelsey, however, are more apt to bear a good crop after such winters than trees of most apricot varieties.

American Plums.—Buds of one of the American species, *Prunus americana,* have longer chilling requirements than even buds of apple varieties. This is true of all varieties in the University planting—varieties such as Terry, Hawkeye, Wyant, and Hammer. Even at Davis they may not be in full blossom before the middle to the last of April. After the warmest winters at Berkeley they are much later, most of the buds never opening. They respond rather well to oil emulsion applied early in January.

Other American species of plums, such as *Prunus hortulana* and *Prunus munsoniana,* have long chilling requirements, but not so long as *Prunus americana* or *Prunus nigra.*

Sweet Cherries.—After moderately warm winters, like those in the Sacramento Valley, buds of most varieties of sweet cherries, *Prunus avium,* are delayed a little more than buds of common peach varieties such as Elberta and Phillips Cling. For example, in New York after its long winters, sweet-cherry varieties blossom as early as peaches or a little earlier; while at Davis, with winters a little too short to break the rest period completely, sweet-cherry varieties tend to blossom later than most peach varieties.

After the warmest winters in southern California, sweet-cherry buds are delayed greatly but tend to open eventually better than peach buds. Apparently, after there has been some winter chilling, long-continued dormancy tends to serve as a substitute for the remaining part of the chilling requirement better with sweet cherries than with peaches. Sweet-cherry trees seem to be less apt to shed their buds during warm winters than peach or apricot trees.

The delay in blossoming caused by warm winters is greater for some varieties, such as Bing, Lambert, Napoleon (Royal Ann), and Yellow Spanish, than for others, such as Republican (Black Republican), Black Tartarian, Burbank, and Chapman. This difference in chilling requirement will sometimes cause trees of a variety to blossom too late to receive pollen from trees of another variety depended upon to supply pollen for them. After such winters, it is not always possible to determine whether the failure of trees to set fruit is due to lack of pollen or to shedding of flowers caused by delay in opening.

After warm winters in northern California, sweet-cherry buds will open earlier if the trees have been sprayed with oil in early January.

Sour Cherries.—The varieties of sour cherries, *Prunus cerasus,* that have been tried where the winters are warmest in southern California have longer chilling requirements than most sweet-cherry varieties have. They may be delayed, somewhat injuriously, in years when trees of

most peach varieties and sweet-cherry varieties, and some apple varieties, start well enough. Figure 18 shows strikingly the delay in starting that may result from insufficient chilling. The scion at *a* was held during December and January in cold storage at 32° F and grafted early in February. It was in full blossom by March 14 and had shoots 8 inches long by April 8. The remainder of the top had been grafted the year

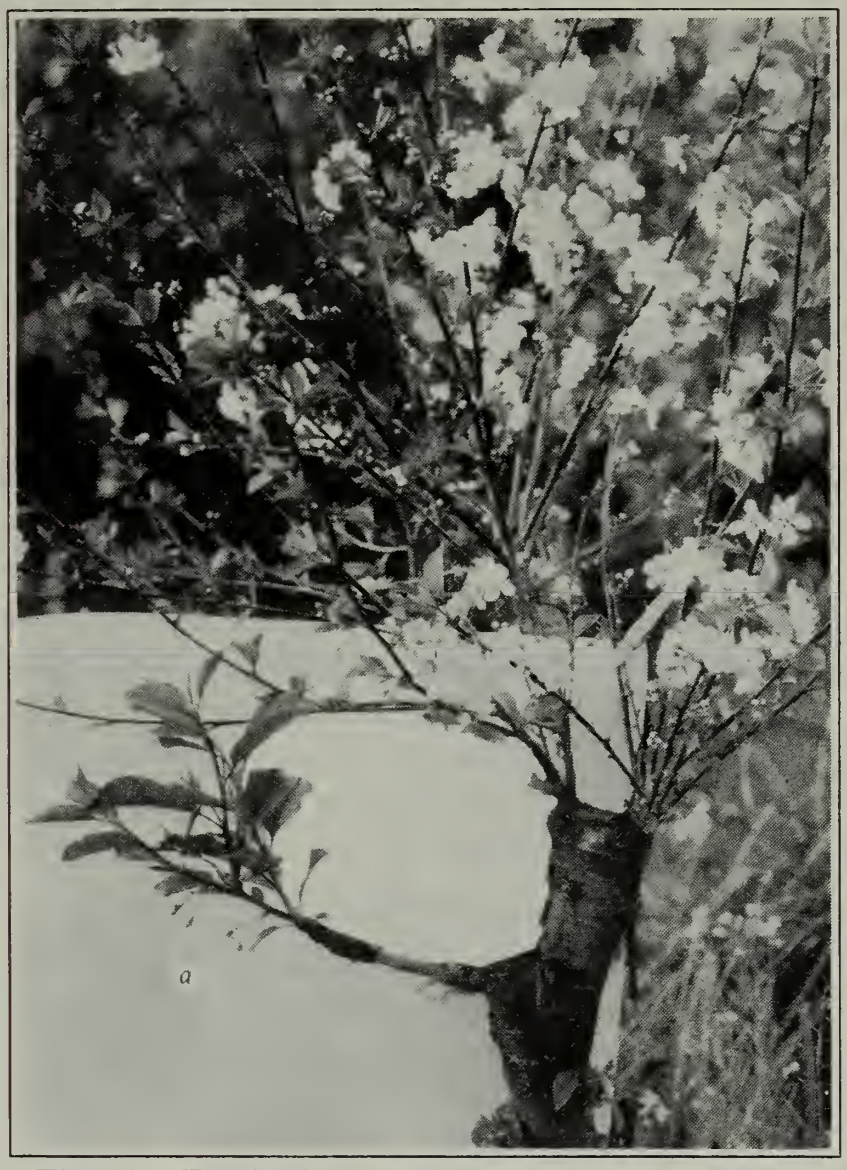

Fig. 18.—English Morello cherry tree, April 8, 1936: *a*, growth from a scion that was set early in February after being held at 32° F for two months; its leaf buds and fruit buds opened more than a month earlier than most of those on the remainder of the tree, which had the chilling supplied by the warm Berkeley winter of 1935–36.

before and was outside during the warm winter of 1935–36. Less than half of its blossoms were opening by April 8 and blossoms were still opening after May 1. They would, of course, have opened as early as blossoms at *a* if they had been chilled enough. Even on the backward part of this tree buds opened earlier than on neighboring trees, because this one was sprayed in January with linseed oil.

The fruit buds of sour cherries are not so apt to be shed as apricot or peach buds, and, on English Morello at least, a tree badly delayed in starting may eventually have a full blossom. Sometimes enough of these blossoms set for a fair yield of late fruit. In other years, however, such late blossoms may set very few fruits, or none.

Montmorency and Early Richmond trees seem to be injured more by very warm winters than English Morello or Empress Eugenie trees. In sections with winters too warm to break the rest period, sour-cherry buds seem to respond better to a spraying with 2 per cent of oil containing 3 per cent of dinitro-o-cyclohexylphenol (that is, 0.06 per cent in the spray) than to a spraying with linseed oil.

China Cherries.—The Chinese cherry, *Prunus pseudocerasus,* has a very short chilling requirement and will open its buds early after the warmest winters in Berkeley.

GRAPES

Vinifera (Old World) Grapes.—Vines of at least some varieties of vinifera grapes, *Vitis vinifera,* require some chilling. For example, in some of the warmest parts of southern California, buds of Thompson Seedless (Sultanina) have been observed to start earlier and more uniformly if the vines were in the shade of an evergreen hedge, or of something else, during December and January. On the other hand, vines of the varieties observed seem to start much better than apple trees or peach trees, of the common varieties, after the warmest winters at Ontario and some other areas in southern California.

Labrusca (Slipskin, American) Grapes.—The labrusca species, *Vitis labrusca,* is native to the rather cold winters from north Georgia to the New England states, yet it has an exceedingly short chilling requirement, so short in some varieties that it can be replaced as early as autumn by such influences as pruning wounds near the buds. In parts of Berkeley above the tule fogs, where the winters are warm enough for at least slow growth nearly all the time, shoot growth will start in the middle of winter on some varieties, especially the labrusca-vinifera hybrids Catawba, Herbert, Massasoit, and Barry. The flowers on such shoots usually do not set fruit. Even Concord, Worden, Diamond, and Niagara vines may start growth too early in some Berkeley winters to bear good flowers. Pure vinifera varieties observed there, such as Muscat Hamburg and Chasselas Dore, remain dormant through these winters and start growth satisfactorily in spring.

Pierce, Isabella, and Ione, are labrusca varieties that have long been known to hold their buds dormant until spring and to bear well after

the warm winters in coastal sections of California. The excellent new varieties from the New York Experiment Station, Golden Muscat and Urbana, fruit well in such sections.

In the Sacramento, San Joaquin, and other valleys, where most of the winters are cold enough to prevent growth until spring, such labrusca-vinifera hybrids as Barry and Catawba set somewhat better crops than in sections with winters as warm as those in Berkeley.

Other Grapes.—Two varieties, Delaware and Berckmans, from crosses among the American species, *Vitis vulpina, V. labrusca,* and *V. aestivalis* var. *bourquiniana,* hold dormant during Berkeley winters well enough, and Berckmans fruits rather well.

While some species of grapes observed have rather slight chilling requirements, it is interesting to note that one Chinese species grown as an ornamental, *Vitis davidi,* has a longer chilling requirement than even Northern Spy apple. The first few buds were just bursting in the spring of 1936 in the Berkeley hills by April 29, when at Sebastopol, where the winters are colder, shoots were nearly 2 feet long.

SMALL FRUITS

Strawberries.—There is some evidence that strawberry plants sometimes go into a slight rest period and require a little chilling before their buds will grow freely. Our observations, however, have not been extensive enough to justify opinions. The response of strawberry varieties to temperature and to other climatic influences is very complicated. Few workers in any state have studied them comprehensively. Anyone interested in them should read the reports of Darrow and his associates in the United States Department of Agriculture Bureau of Plant Industry, one of which is cited below.[22]

Raspberries.—In sunny positions above the winter fogs in Berkeley, all the buds often fail to open on Cuthbert red-raspberry canes in spring. This seems to be due to the warm winters, but observations have not been extensive enough to give conclusive evidence. In southern California, even after the winter of 1936–37, with its unusual amount of chilling, Cuthbert red raspberry and Munger black raspberry started earlier in shady places than in places exposed to the sun during the winter months. After warmer winters, these varieties fail to bear satisfactory crops, and most other varieties show some delay in growth.

Blackberries and Dewberries.—A small number of the northeastern varieties of blackberries have been observed in the state recently. These

[22] Darrow, George M., and George F. Waldo. Responses of strawberry varieties and species to duration of the daily light period. U. S. Dept. Agr. Tech. Bul.453: 1–31. 1934.

seem to be delayed a little in starting after the warmest winters in southern California but to fruit satisfactorily.

Careful observations of Young (Youngberry) and Boysen vines indicate that they also are delayed in starting after the warmest winters in southern California, but eventually produce an abundance of leaves and a good crop: vines in the shade of evergreen trees during winter, or vines lying on the ground shaded by their own leaves, start 10 days to 2 weeks earlier than vines exposed to the sun during the winter months.

Gooseberries.—At least some of the varieties of European gooseberries, *Ribes grossularia,* start very weakly after any but the coldest winters in Berkeley. In the part above the winter fogs, only a few buds or none at all start on Chautauqua and Portage after the warmest winters. Several other European varieties and Poorman, a hybrid between an American species and a European variety, also start weakly in spring because of lack of winter chilling. In sections where there is a little more winter chilling than in Berkeley but where the summers are cool and rather humid, there have apparently been fairly satisfactory results with Oregon Champion, probably also a hybrid between American and European gooseberries.

In southern California, gooseberries start satisfactorily in spring only at rather high elevations, where it is usually too dry for them to do well in summer.

Currants.—The common European currant seems to do a little better than most varieties of gooseberries in the San Francisco Bay area. The Cherry variety fruits rather well in sections where the winters are a little colder and foggier than in Berkeley. In such districts on hillsides above the densest winter fogs, plants are observed to start growth in spring a little later than plants on lower ground, but they eventually make good growth and bear well. There is not enough experience with other varieties to give evidence as to how they would behave in such localities.

In southern California, currants, like gooseberries, do not start growth or blossom satisfactorily after the warmest winters except at rather high elevations too far from the ocean for the summers to be sufficiently cool and humid for currants.

NUT-BEARING TREES[23]

Walnuts.—Varieties of Persian walnuts, *Juglans regia,* often called English walnuts, grown in California are mainly from three strains: (1) the Santa Barbara soft-shell, of which Placentia is the best-known

[23] In addition to almonds (p. 34).

representative, Ehrhardt, Chase, Wasson, and Pride of Ventura being other representatives, all grown mainly in southern California; (2) French varieties, Franquette and Mayette, and seedlings from them, such as Concord and Payne, all but Payne grown mainly in northern California; and (3) Eureka and Blackmer, from trees of Persian walnuts that were here before the introduction of the Santa Barbara soft-shell and the French varieties, these also grown mainly in northern California. A considerable number of trees of Eureka and more of Payne have been planted in southern California. Enough trees also of each of the other northern California varieties have been planted in southern California to give information as to how they behave after warm winters.

All the northern California varieties have rather long chilling requirements, Franquette and Mayette the longest (as long as that of an average variety of apple), Payne the shortest, Concord a little longer than Eureka and Blackmer. There seems never to be injurious delay of the buds of these varieties in northern California, however, unless possibly some of the dying-back of long shoots on young trees is due to their not having had chilling enough to permit the buds to start: more chilling is required to enable the buds toward the ends of long shoots to start normally in spring than to enable buds on short, early-maturing shoots to start.

Franquette and Mayette will show some delay in starting after even the coldest winters in southern California, and their starting is greatly delayed, sometimes up to July, after the warmest winters. Eureka, Blackmer, Concord, and Payne, also, are injuriously delayed after warm winters in southern California, Payne less than the others.

After most winters, trees of all these varieties, with the possible exception of Payne, start later in southern California than in northern California, much later after the warmest winters. For example, by May 9, 1935, at Redding and Davis, Franquette and Mayette trees had leaves one-half grown, Payne, Blackmer, and Eureka, had leaves full grown, all branches of all trees in nearly the same stage of development. At the same time in districts of southern California, Franquette and Mayette showed no buds breaking, Eureka had a few scattered leaves (fig. 19), some just starting, some half grown, Concord had very few buds breaking, Payne had no leaves more than half grown, and Blackmer leaves were only about 10 per cent of full size. In southern California, on all except Blackmer, not nearly so many buds were growing as in northern California: the chilling was enough to permit growth in some buds but not in others on the same tree; if the chilling had been ample as it was in northern California, buds on a tree, and on all other trees in the same

planting, would have started approximately together. At this time, trees of Placentia (fig. 19) had leaves developed about as far and nearly as evenly as leaves on Eureka and Payne at Redding and Davis. However, in some especially warm districts free from fogs even Placentia and other southern California varieties were still nearly bare of leaves. There had, of course, been more warm spring weather in southern California than at Davis or at Redding, and trees such as the fig, with little or no chilling requirement, were more advanced in southern than in northern California.

Fig. 19.—*A*, Eureka walnut tree; *B*, Placentia, May 9, 1935, after a warm winter near Los Angeles, California.

Although the southern California varieties have short chilling requirements, there is not always enough cold weather in some districts to cause the buds to open satisfactorily. In fact, the crop in the southern part of the state has been reduced greatly after some especially warm winters. This reduction was due in part to dropping of very small fruits after they had grown slightly from flowers that opened very late. Probably many of these fruits were from flowers that had never been pollinated; the pollen may all have been shed before the pistils on the latest shoots to grow were ready for it. The reduction in crop was due in part also to failure of many buds to grow after the warmest winters.

In figure 20 the crop in southern California counties for each year since that of 1917 is shown by the black bars in millions of pounds. Each bar crossed with diagonal lines shows the mean temperature for Decem-

ber, January, and February, preceding the crop indicated by the black bar to its right. Since nearly all the crop in those counties is from Santa Barbara soft-shell seedlings and varieties, any large reduction must be due to an influence that affects those varieties. The smallest crop, that of

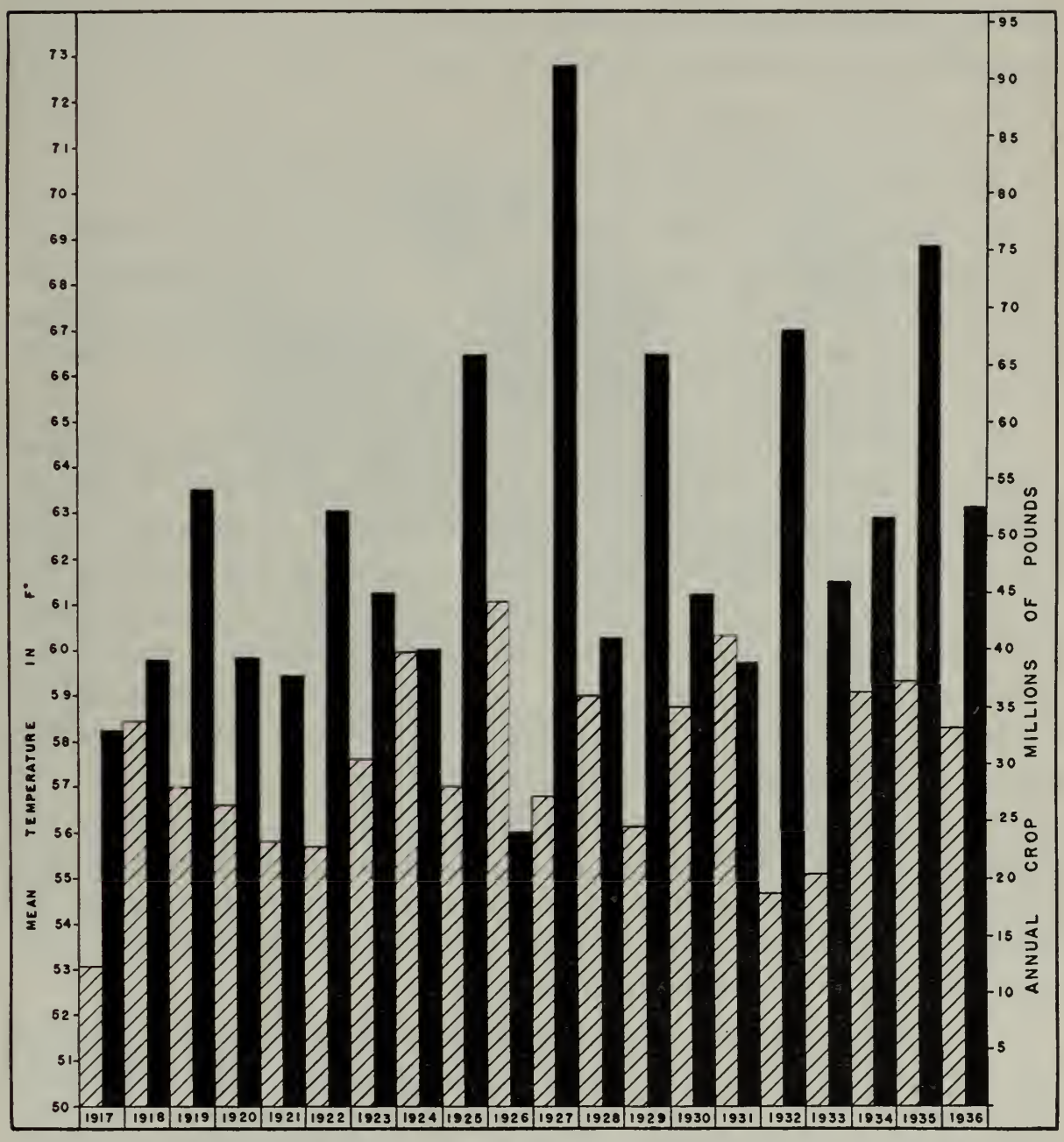

Fig. 20.—Black bars: walnut crops, orchard run, in southern California counties. White bars with diagonal lines: mean temperatures, in degrees above 50° F, for December, January, and February; each white bar gives the temperature for the winter preceding the crop indicated by the black bar to its right.

1926, followed the warmest winter. The crops of 1924, 1928, 1930, 1931, and 1934, were also reduced considerably by the warm winters preceding. The small crop in 1933, after a good winter for chilling, was caused by a spring frost.

For some reason the crop of 1935 was not greatly reduced by the

rather warm winter preceding it. Female flowers of the walnut are borne at the ends of small shoots. Buds which produce these shoots are not shed in warm winters, but many remain dormant. Dormant buds two years old or older, as with those of peach trees, seem not to require so much chilling as one-year-old buds require before they will grow. All small shoots, even those which start after the first shoots have been killed by frost, tend to have flowers. Possibly in many orchards in southern California a considerable part of the crop of 1935 was from buds formed in 1933 that had remained dormant in 1934, following another warm winter. We have no accurate observations concerning this problem. The crop of 1931 does not seem to have been increased in this way, although many buds had remained dormant in the spring of 1930, which followed another warm winter. The winter preceding the crop of 1931, however, was warmer than that preceding that of 1935: it may have been too warm for even dormant buds to grow normally in spring.

The excellent crop of 1927 was preceded by a mean temperature for December, January, and February, at Los Angeles, of 56.7° F, 4.3° F below that for the same months preceding the very small crop of 1926. The mean temperature for these months in Los Angeles preceding the spring of 1937 was 53.9° F. In that spring on trees of these southern California varieties nearly all buds on the twigs, lateral as well as terminal, grew. In other words, these reductions in crop were caused by winters only 3° to 7° F warmer than those which supplied chilling enough for unimpeded opening of the buds in spring.

In concluding that the light crops in some years were due to the warmer winters preceding, we are, of course, not dependent upon data in figure 20 alone. We visited the orchards each spring and observed the delayed starting or the failure of most of the buds to grow, as well as the light setting after the warmest winters.

In years when insufficient chilling prevents many of the one-year-old buds from growing, some of the dormant buds that grow, especially those down in old wood, make long shoots that hang downward from the weight of their luxuriant foliage and grow so late that they are in danger of being killed by early frosts.

Unlike apple trees, walnut trees are slow to go into the rest period in summer. There are usually several cycles of growth. In midsummer or later, a walnut tree may form terminal buds on all its shoots and remain without growth long enough for an apple or a pear tree to go completely into the rest period; then, later, new growth may start from some of the shoots or nearly all of the rather long ones. This habit permits the walnut tree to grow so late, when temperature and moisture conditions are

favorable, that it is in much greater danger from early winter frosts than any of the common deciduous fruit trees.

The California black walnut seems to have a very slight chilling requirement, and the eastern black walnut less than some varieties of Persian walnuts, such as Franquette.

Chestnuts.—Varieties, seedlings, or hybrids, of four species of chestnuts are being tried in California. These are *Castanea molissima,* the

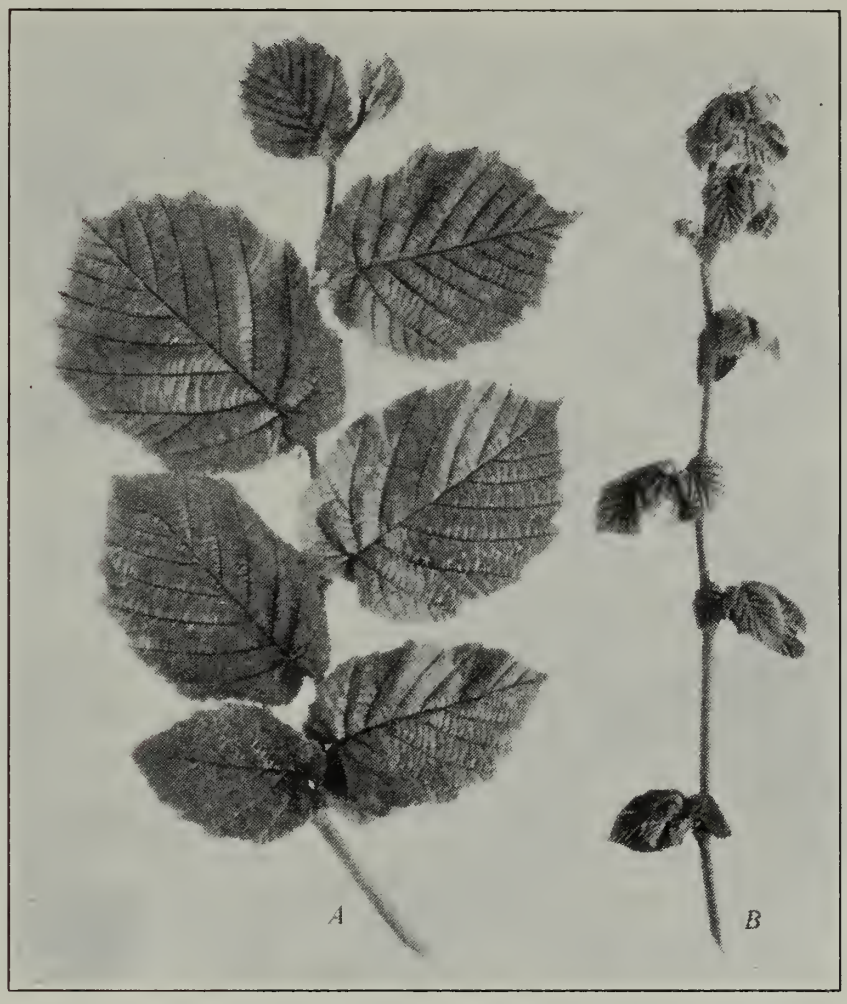

Fig. 21.—Growth from filbert buds, Macrocarpa variety, at Berkeley, by April 17, 1936: *A,* shoot from a bud on a scion that had been chilled two months at 32° F before it was set; *B,* growth just starting from buds exposed to the warm winter.

Chinese chestnut, *C. dentata,* the American chestnut, *C. sativa,* the European, sometimes called the Italian or the Spanish chestnut, and *C. crenata,* the Japanese chestnut. After the warmest winters in Berkeley, Chinese chestnut trees start early, all their buds at about the same time, as if their chilling requirements had been fully satisfied. This is true also of Boone and Colossal, probably hybrids between American and Japanese chestnuts. On the other hand, Quercy, a variety of the European chestnut; Progress and Rochester, American-European hybrids;

and the ornamental variety, Fountain, show some delay and unevenness in opening of the buds, as if somewhat more chilling would be required for unhindered opening. Enough buds grow for satisfactory development of the trees, however. In Orange County, some unnamed old chestnut trees, probably European, showed injurious delay in starting of the buds after one of the warmest winters. Our observations suggest that some chestnut varieties may require more chilling for best development of the trees than is supplied by the warmest winters in southern Cali-

Fig. 22.—Geant de Halle filbert branches taken April 16, 1936, each about one-third of natural size: *A*, from a tree at Davis; *B*, from one at Berkeley. At this time, plants with no chilling requirement were more advanced at Berkeley than at Davis.

fornia but not so much as the average northern California walnut variety requires.

Filberts, or Hazelnuts.—In Berkeley, on trees of nearly all filbert varieties observed, there is some delay in starting of the leaf buds after winters warmer than the average. Barcelona shows less delay than any other except Fertile de Coutard; yet Barcelona trees that were held in cold storage at 32° F for two months and then put in the orchard with the others, had leaves 1¾ inches across when none were more than ¼ inch across on trees that had remained in the orchard. Trees of Du

Chilly, Nottingham, Prolific Cobb, Geant de Halle, Cosford, Emperor, Gassoway, and Macrocarpa (fig. 21), are delayed as much as Delicious apple trees or more, in springs after warm Berkeley winters. Eventually, however, enough buds grow to make the tree as a whole show much better development than Delicious apple trees show after those winters. Trees of Barcelona and of some varieties with longer chilling requirements will make good growth, although they start late in spring, even after the warmest winters in southern California. Fruiting, however, has not generally been satisfactory.

On most varieties the opening of pistillate (female) flowers is delayed and straggling in Berkeley winters if there is not enough chilling. Pistillate flowers on Barcelona trees held for two months at 32° F opened earlier and more nearly all together than flowers on trees left in the orchard. On the other hand, development of catkins and shedding of pollen are not delayed so much, are sometimes even hastened, by warm winters. For these reasons, it may require several varieties shedding pollen through a long period, some shedding it as late as March, to give satisfactory pollination, where the winters are as warm as some of those in Berkeley. In the Sacramento Valley and its foothills there seems always to be chilling enough for early starting of growth (fig. 22) and there is no evidence that delay in the opening of pistillate flowers complicates the pollination problem. Shedding of the catkins in autumn seems to be the chief cause of failure to fruit.

CHILLING REQUIREMENTS OF SOME ORNAMENTALS

Most of the observations on ornamentals were made at Berkeley and at Davis or Sacramento. Only the few species that some of us happened to have experience with are mentioned. There are many other species of ornamental plants that may be influenced by insufficient winter chilling. The examples discussed, however, may help gardeners to determine for themselves whether or not any unsatisfactory spring behavior they encounter with other plants is caused by warm winters.

POME-FRUIT ORNAMENTALS

The common quince, page 31, discussed under "Pome Fruits," can be a very beautiful ornamental, and some closely related species are used only as ornamentals.

Chinese Quince.—The Chinese quince, *Chaenomeles sinensis,* starts growth and blooms satisfactorily after the warmest winters in the warmest parts of Berkeley. In fact, new leaves and even flowers often appear before the old leaves have all fallen off.

Japanese Quince and Dwarf Japanese Quince.—Buds of both the Japanese quince (*Chaenomeles lagenaria*) and the dwarf Japanese quince (*Chaenomeles japonica*), especially the latter, seem to be delayed in starting in spring after the warmest winters in the hills of Berkeley. Bushes observed after the cold winter of 1936–37 bloomed and started growth better than they had in other years after warmer winters. Ob-

Fig. 23.—English hawthorn trees, photographed April 16, 1936: *A*, tree growing at Davis; *B*, tree growing on high ground at Berkeley.

servations, however, have not been comprehensive enough to justify an unqualified conclusion that the straggling appearance and relatively late starting in these positions may not be due to some other influence.

Medlar.—The medlar, *Mespilus germanica,* is sometimes grown for the fruit, which can be used to make a tart, rather astringent jelly, or for eating, if held until it is soft enough to lose its astringency. The tree is beautiful; and after the warmest winters in Berkeley, the leaves come out, nearly all together, late in March. The large, single flowers, terminal on leafy shoots, are a little later than quince flowers. The foliage, with beautiful autumn colors, holds until nearly Christmas.

English Hawthorn.—Trees of the English hawthorn, *Crataegus oxyacantha,* and of some botanical varieties and closely related species, bloom and start growth late enough to give them a ragged appearance after the warmest winters in the warmest parts of Berkeley (fig. 23, *B*). They may start evenly enough to give it a rather beautiful appearance in the parts of Berkeley, Oakland, and San Francisco that have the most win-

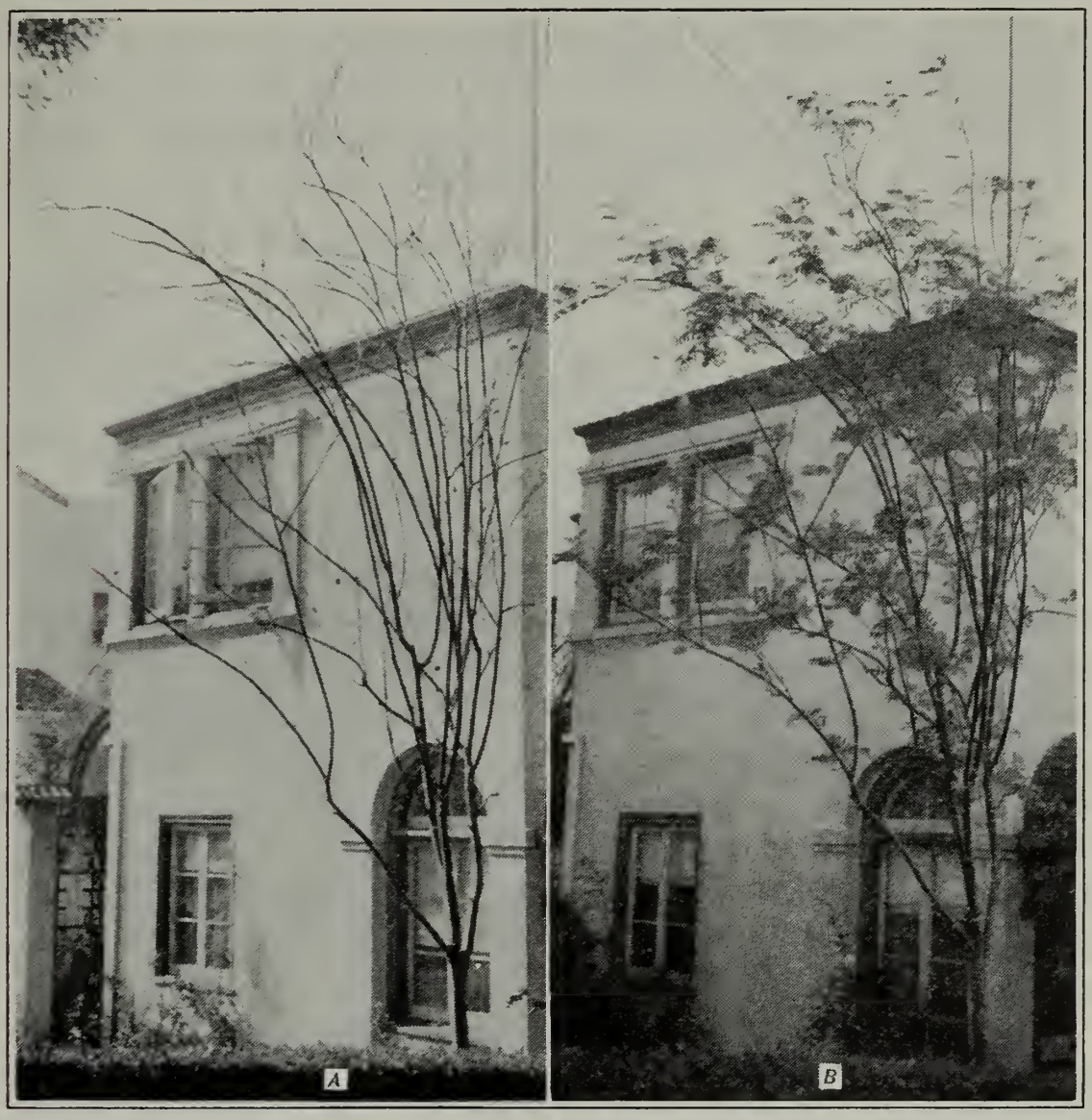

Fig. 24.—Mountain ash or rowan tree (*Sorbus aucuparia*) : *A,* May 10, 1936; *B,* same tree April 20, 1937. This tree, like a number of others in the hills of Berkeley, had only a small number of its buds open by the first of June in 1936; it was well covered with foliage by April 25, 1937, after a colder winter.

ter fog, though they start earlier and more luxuriantly after winters like those of Sacramento and Davis (fig. 23, *A*). The tree in figure 23, *B,* did not show this straggling appearance when growth started after the colder winter of 1936–37.

European Mountain Ash or Rowan Tree.—The European mountain ash, *Sorbus aucuparia,* is usually propagated from seeds, without selection, in California. The different individual trees, therefore, vary as

much in chilling requirements as different varieties of walnuts or of apples. For example, in the spring of 1936, one tree was in full leaf and full bloom before April 11, while other trees in the same part of Berkeley were not advanced as far by June 1 and never had more than a few buds open in one season (fig. 24, *A*). After the colder winter of 1936-37, this same tree (fig. 24, *B*), like all other mountain ash trees that started so late and weakly after warmer winters, was in full leaf on April 25, less than 10 days after the earliest trees to reach full leafing in the hills of Berkeley. If one should want early luxuriant growth every year, one could graft over such a tree as that in figure 24, using scions from a tree known to have a shorter chilling requirement.

STONE-FRUIT ORNAMENTALS

Stone-fruit ornamentals have not been observed systematically. Some of them, like the pink, double-flowered plum (known in the trade as *Prunus blireana*) and the purple-leaf plum (known as *Prunus pissardi*), come out with little delay except on very long twigs after the warmest winters in the warmest parts of Berkeley.

Flowering Almond.—An old favorite, *Prunus glandulosa,* the small bush known over much of the United States as the flowering almond, although it is more closely related to the cherry than to the almond, is grown for its very early, pale-pink double flowers. In the hills above the winter fogs in Berkeley, it is not early : its blooming is so greatly delayed in springs after the warmest winters that a number of the flowering-peach varieties and other flowering trees related to the stone fruits precede it. Its leaf buds are delayed even more, so that it tends to die back to new sprouts from old dormant buds. It does much better in the lower parts of Berkeley and in parts of San Francisco where the winters are foggier.

Flowering Peaches.—The flowering peach varieties are of the same species, *Amygdalus persica,* as those grown for fruit, but they seem to have come from strains with short chilling requirements. Most of them bloom satisfactorily in parts of Berkeley with the warmest, sunniest winters. A few, like the common white one, bloom somewhat later there than in Davis or in the parts of Berkeley where the winters are foggier.

On trees even of the varieties with short chilling requirements, long shoots that grew late the year before may bloom a week or two later than shorter shoots. If one should want the flowers opening nearly all together to make the most striking effect, one could prune rather lightly, cutting back to laterals after the bloom, or, if one should want flowers through a longer period, one could prune severely as soon as the bloom is gone, so as to stimulate long, late growth.

Oriental Flowering Cherries.—Among the species and varieties of Oriental flowering cherries, some have chilling requirements short enough to permit them to bloom and grow satisfactorily in springs after the warmest winters in Berkeley. This is true of the rosy, pendulous-flowered Taiwan cherry, *Prunus campanulata;* of the drooping cherry, *P. subhirtella;* and of such single-flowered varieties as Yoshino and Akebono in the species *P. yedoensis.* Some of the double-flowered varieties such as Shirotae (Mount Fuji), Shiro-fugen (Victory), Kwanzan (known also as Kanzan), Amanogawa, and Shogetsu, of the species *P. serrulata,* may do fairly well after the warmest winters in the hills of Berkeley. The chilling requirements of some of these double forms is fully equal to that of English Morello cherry; and, like English Morello, they tend to be delayed greatly after warm winters but tend eventually to have enough flowers open together to make a rather good appearance. All these double varieties bloom earlier and more abundantly after colder winters like those in Sacramento, or like that of 1936–37 in Berkeley.

Without full distinctions as to kinds and varieties, flowering cherries are reported not to do well in parts of southern California where the winters are warmest.[24] It is not made clear whether this observation concerns only the more popular, double-flowered varieties or all varieties of all the species mentioned. Observations in Berkeley would lead one to expect *P. campanulata, P. subhirtella,* and the varieties Yoshino and Akebono of *P. yedoensis* to do well also in southern California.

No information is available as to whether or not flowering cherries, when sprayed late in a warm winter with oil sprays or with oil containing dinitro-o-cyclohexylphenol, will bloom earlier and better as English Morello cherry does.

MISCELLANEOUS ORNAMENTAL TREES AND SHRUBS

North American Pawpaw.—Although the pawpaw, *Asimina triloba,* bears edible fruit, it would be grown only in a home planting with ornamental trees or bushes. Its chilling requirement is longer than that of Bartlett pear or Northern Spy apple. In 1936 none of its buds were showing green before May 5 in the low part of Berkeley. Above the winter fogs it was later; after some warmer winters, it failed to start at all but died back nearly to the ground and sprouted the next spring. It responds rather well to oil emulsion applied early in January.

Elm.—Trees of the American elm, *Ulmus americana,* are usually propagated as seedlings and therefore vary greatly in chilling require-

[24] Russell, Paul. The oriental flowering cherries. U. S. Dept. Agr. Cir. 313:1–72. 1934.

ments (fig. 25). Along a street in Berkeley, among fifty-two trees, some were 50 days later than others in leafing after the warm winter of 1933–34; the same late trees were only 22 days later than the earliest after the cooler winter of 1936–37, in spite of a slow, cool spring. After an average winter at Sacramento and Davis, there is still less difference in time of leafing of different trees, but there is not always chilling weather enough

Fig. 25.—American elm (*Ulmus americana*) seedlings with different chilling requirements. The trees are growing within a few rods of each other on the same street in Berkeley. This contrast was showing throughout April. The tree at the right (*B*) was in full leaf by April 4, that at the left (*A*) by May 15.

to cause buds on all American or European elm trees to open at as nearly the same time as they do after a colder winter like that of 1936–37.

English elms, *Ulmus campestris,* at Sacramento in 1936 showed more evidence than American elms that the chilling requirement was not completely satisfied; and they were a little later in starting, but the differences among them were not so great as among American elms at Berkeley.

The elm did not respond to spraying in January, 1936, with a 5 per cent linseed-oil emulsion.

In cities like Berkeley, where the winter chilling requirement of some trees is so far from being satisfied, one means of preventing a ragged

appearance of seedling elms along a street, for a time in spring, would be to plant grafted trees, the scions all from one original tree. Another would be to grow young seedling trees where the winters are warm, so that they could be classified in the nursery as to time of starting in spring. Then only early-starting trees could be planted along some streets; the late-starting ones could either be discarded or planted all together on other streets.

In contrast with *Ulmus americana* and *U. campestris, U. parvifolia* seems to have little or no chilling requirement and will start, all trees together, before the old leaves have fallen.

Plane Trees (Sycamores).—Trees of the London plane, *Platanus acerifolia,* and of the California plane tree, *Platanus racemosa,* have very short chilling requirements. In Berkeley after the warmest winters, the leaves come out early in spring and at nearly the same time on all trees.

Arizona Ash.—The Arizona ash, *Fraxinus velutina,* like the plane trees, has only a slight chilling requirement. It comes out early in Berkeley after all winters. Although it is propagated from seed, all the trees come out at rather near the same time.

Common and Persian Lilacs.—Bushes of the common lilac, *Syringa vulgaris,* and the Persian lilac, *S. persica,* come out early enough after warm winters, about as early in Berkeley as in Sacramento, but the clusters are small and less attractive in Berkeley. After the colder winter of 1936–37, people in Berkeley, generally, noted that the appearance of lilacs was strikingly better than during the three preceding seasons, each following warm winters. There seems to be some dying of the flowers in the bud during warm winters. Lilacs seem to bloom about as beautifully in Sacramento as in the colder climates of the Northeast. After the rather cold winters of the Antelope Valley in Los Angeles County, lilacs produce long clusters, while in the warm valleys of the same county the clusters are short and the buds uneven in time of starting. In such warm valleys, bushes in the shade during the winter months produce good clusters. Treating branches with ethylene has caused them to produce good clusters after winters so warm that most of the flower parts died in the buds on untreated branches.

Golden Bells.—The golden bells, *Forsythia suspensa* and other species, have short chilling requirements but seem to shed their buds rather badly during warm winters. In Berkeley after the cold winter of 1936–37 buds were not shed and all opened together about March 1, to make a very beautiful effect.

European White Birch.—The European white birch, *Betula pendula,* is an example of kinds whose chilling requirements, though short, may

not be well adjusted to some winters. Only a few weeks of chilling weather is enough to permit its buds to open. If there is a little chilling weather in autumn, or some injury, such as aphid punctures, at the buds to serve in the place of chilling, and if this is followed by warm weather, some of the buds may start growth. These winter twigs may not lose their leaves until spring. Their buds are deeply in the rest period at the time growth starts from normal buds on the same tree. Such autumn or winter twigs tend to die during the summer. In Berkeley after warm winters, there are sometimes enough of such dead twigs on many trees to give them a ragged appearance.

If the chilling requirement were long enough to hold the buds dormant until spring, or if most Berkeley winters, like that of 1936–37, were cold enough to hold them dormant, birch trees would be healthier in appearance. In such climates, if the birch tree is placed in good rich soil, so that it grows rather late and is pruned enough in winter to invigorate it considerably, it will show less tendency for new growth to start in early winter and will, therefore, have a more attractive appearance in early spring.

Golden Chain.—One species of golden chain, *Laburnum anagyroides,* will start growth and bloom early after the warmest winters in Berkeley. Others, such as the Scotch laburnum, *L. alpinum,* will be greatly delayed after the warmest winters there.

The Vossi variety (called in the trade *Laburnum vossi* and said to be a hybrid between these two species) may, when growing above the fog line in Berkeley, bloom in a straggling way from late April to September after especially warm winters, though after cold winters such as 1932–33 or 1936–37, it will finish blooming by early June. It has not responded to spraying in January with linseed-oil emulsion. Where winters are too warm for beautiful growth and blooming to follow, the best treatment for this variety is to graft it over, using scions of *Laburnum anagyroides,* the kind with grayish down on the underside of the leaves.

Wisteria.—Vines of the wisteria have rather short chilling requirements, those of some varieties considerably shorter than those of others, but vines of all varieties come out satisfactorily after the warmest Berkeley winters. Buds on long shoots are delayed some in coming out. For example, above the fog line in Berkeley, flowers of a variety with a shorter chilling requirement than most wisteria varieties have, against the same side of a house, were open 20 days earlier in the spring of 1931 from buds on short twigs and spurs than from buds on a shoot 18 feet long. Buds near the base of such a shoot open first and those near the apex last, the difference being greater the warmer the preceding winter.

Mock-Orange. — The mock-orange, *Philadelphus* spp., sometimes called syringa, has a considerable number of species and hybrids. Most of them have short chilling requirements, and the flowers come out beautifully after the warmest winters in Berkeley. A very widely grown strain of the large *Philadelphus coronarius,* however, has a rather long chilling requirement, especially in the buds on long shoots. If, in pruning, these long shoots are removed and the brushy short growth left,

Fig. 26.—Snowball flower heads from low ground in Berkeley, about one-third of natural size: *A,* from a low branch that during the winter was in the shade of an evergreen shrub; *B,* from an upper branch that was exposed to the sun during clear days in December and January.

flowers and leaves come out nearly enough together to give a beautiful effect in May and early June, where the winters are no warmer than those in Berkeley. If the long shoots are left, in sections with warm winters, only buds near the end may grow and bloom, so that long bare spaces are left below to give a straggling effect.

Snowball.—The snowball, *Viburnum opulus* var. *sterile,* has a rather moderate chilling requirement and tends to come out nearly as early in Berkeley after warm winters as in Sacramento, but the flower heads tend to be much smaller. After the warm winter of 1935–36 in Berkeley, the flower heads were larger on the parts of a bush that were in the shade during December and January than on the upper parts where the buds

were warmed by the sun on clear days. The head at figure 26, *A*, was typical of those in the shade and that at 26, *B*, of those in the sun during winter in the low part of Berkeley. Heads were still smaller than *B* at some higher positions with sunnier weather in Berkeley, and larger than *A* after the greater amount of winter chilling in Sacramento. In the spring of 1937, following a cooler winter, flower heads on twigs that were in the sun during winter days were not so small as in 1936, but they were a little smaller than heads on twigs that were in the shade during the winter. In other words, even the chilling in the exceptionally cold winter of 1936–37 was not enough to permit the most luxuriant spring blooming; but in Berkeley, as well as in other places with winters warmer than those in the great valleys, it was enough to permit better blooming than had been seen for several years.

Other *Viburnum* species, especially *V. carlesii*, seem to be weakened in flowering after the warmest winters in the part of Berkeley above the winter fog line, but observations have not been extensive enough for certainty.

Weigela.—Weigela florida, sometimes listed in catalogs as *Diervilla florida*, the most common species of this genus, has a short but adequate chilling requirement. Although it seems never to start too early in winter, it comes out, nearly all buds together, in spring, even after the warmest winters in Berkeley.

HERBACEOUS AND BULBOUS PLANTS

Bleeding Heart.—Bleeding heart, *Dicentra spectabilis*, is among the most unsatisfactory of all plants observed after the warmest winters in Berkeley above the fogs. After a moderate winter there, it will send up a short stem that bears only a few leaves but a good cluster of flowers, the flowers being more conspicuous because of the sparse foliage. After the warmest winters, it may not grow at all or it may send up a small cluster of flowers but no leaf growth.

Such a plant that had remained dormant except for a few flowers until May 24 was dug up and held in cold storage at 32° F for 36 days, then set out of doors, where it started growth quickly enough to be 4 inches high in 15 days, a foot high in 47 days. In 1934–35 it was held at 32° during the winter. Then, out of doors, it grew nearly 2 feet high and bloomed well in 1935. It was left out of doors during the warm winter of 1935–36 and, in the spring of 1936, died down after sending up a cluster of flowers and a few leaves on a stem about 4 inches high. After being held in a shaded chest that was open at night to receive the coldest air but closed in the daytime, during the colder winter of 1936–37, it grew and bloomed well.

Figure 27 shows plants from two bare roots of bleeding heart bought and planted at the same time, December 17, 1936. They were badly wilted and there were necessarily large wounds at their bases. It was thought that these influences might break the rest period. Plant *A* was placed directly in the greenhouse. Plant *B* was held in storage at 32° F until January 23, when it was placed beside plant *A* in the greenhouse. They were photographed on February 23. Plant *A* was then put in stor-

Fig. 27.—Effect of chilling on the bleeding heart: *A*, root potted and held in a warm greenhouse December 17 to February 23; *B*, root potted and held at 32° F December 17 to January 23, then kept in greenhouse until February 23.

age at 32° until March 29, when it was returned to the greenhouse. By April 26, it was 18 inches high. In other words, its failure to grow in the greenhouse between December 17 and February 23 was due not to any ailment but only to lack of chilling.

The smaller, California bleeding heart, *Dicentra formosa,* does not require so much chilling, if any.

Goats Beard.—Goats beard, *Aruncus sylvester,* sometimes called a spirea, requires more chilling than is supplied by winters as warm as some of those in the hills of Berkeley. After remaining dormant throughout the summer following a warm winter, it will grow rather well after a second, colder winter. It rarely, if ever, blooms under such conditions, however.

Some Bulbous Plants.—Some of the lilies do not make good growth after the first year in permanent beds in the sections of Berkeley with

the warmest winters, but for most of these it is not certain whether their failure is due to lack of chilling or to other causes. The royal lily, *Lilium regale,* and the Japanese lily, *L. speciosum,* continue healthy for many years and start growth early enough after the warmest winters there.

Some other bulbous plants, especially narcissus species, when left out of doors during the winter or when stored, are influenced in the time and nature of blooming by the temperature while they are dormant;[25] but we have no exact observations to report.

[25] Griffiths, David. Speeding up flowering in the daffodil and the bulbous iris. U. S. Dept. Agr. Cir. 367:1–18. 1936.

SUMMARY

During fourteen years, 1924 to 1937 inclusive, the effects of varying amounts of winter chilling on blossoming and the beginning of growth by deciduous plants in different sections of the state have been observed.

In nearly all sections of California where fruit is grown extensively, the amount of winter chilling is too small for buds to open as quickly or as evenly when spring weather begins as they would in sections with longer, colder winters. This delay is not often injurious north of the Tehachapi Mountains, except in a few areas near the coast. It tends to be beneficial; for delay in opening of the buds tends to reduce the frost hazard.

In some sections south of Tehachapi, however, the effects of the warmest winters are very injurious. Fruit buds and leaf buds that should open in March may not open until May or June, and then only a small percentage may open. Most of the flowers may fail to set fruit. Shoot growth and leaf growth on the tree may be so sparse that there is much injury from summer sunscald and borers.

One of the most injurious results of very warm winters, on species that have only flower parts in the fruit buds, is the shedding of unswollen fruit buds in late winter and early spring. On apricots, and on some varieties of peaches and plums, there is shedding of the buds during or after especially warm winters, even in northern California. On species that have both flowers and leaves in the bud, some of the flowers may die, so that the bud may open without flowers or with two or three flowers instead of about seven.

The amount of fog is important in determining the effectiveness of winter chilling. In sections with much winter fog, trees are less apt to shed their buds unopen or to be too greatly delayed in opening of buds in spring. Winter shade also is beneficial.

There are great differences among deciduous species as to the amount of chilling required for satisfactory opening of the buds in spring.

The characteristic responses to short winters by the species grown for fruit, and by a few of those grown as ornamentals, are discussed.

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